INEQUALITIES IN CHILDREN'S PHYSICAL ACTIVITY AND INTERVENTIONS

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DECLARATION

This thesis is the result of my own work and includes nothing which is the outcome of work done in collaboration except where specifically indicated in the text.

It has not been previously submitted, in part or whole, to any university or institution for any degree, diploma, or other qualification at the University of Cambridge or any other University.

All of the research presented in this dissertation was conducted at the Centre for Diet and Activity Research (CEDAR), under the supervision of Esther M.F. van Sluijs and Jean Adams.

This dissertation does not exceed 60 000 words excluding references, tables, figures and appendixes, as prescribed by the Degree Committee of the Faculty of Clinical Medicine.

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ABSTRACT

There is clear evidence of socioeconomic inequalities in overweight and obesity in childhood. These differences progressively worsen with age ultimately amplifying disparities in morbidity and premature mortality from associated noncommunicable diseases across the life-course.

The well-established benefits of physical activity during childhood in promoting health and reducing future disease risk has led to an international focus on its promotion across populations. Unlike in adults, it is unclear if the accumulation and distribution of physical activity in children differs by socioeconomic position. It furthermore is unknown whether all children benefit equally from current efforts to promote physical activity.

In consideration of these evidence gaps, the aims of this thesis were: 1) to investigate the socioeconomic patterning of children's physical activity behaviour, and 2) to explore if existing intervention efforts are generating differential effects.

The findings from three secondary data analyses suggest that more socioeconomically affluent children accumulate a greater proportion of their daily physical activity from higher intensity activities, which are more strongly associated with lower levels of adiposity. This association was demonstrated both in the UK's Millennium Cohort Study and South Africa's Birth to Twenty Cohort. A subsequent analysis of pooled and harmonized data from 36 European cohorts with accelerometer-assessed physical activity confirmed these findings. It also revealed that irrespective of the national context, children with increased socioeconomic affluence engage in more vigorous physical activity and have lower adiposity despite overall lower levels of moderate-vigorous physical activity.

Investigations of current efforts to promote physical activity were conducted through a two-stage systematic review and meta-analysis. An initial scoping review demonstrated an overall scarcity of published evidence on differential effects by sociodemographic characteristics. Subsequent meta-analyses of data re-analysed by authors revealed that current school-based physical activity interventions are not effective at increasing daily moderate-vigorous physical activity with no evidence of differential effectiveness by a child's socioeconomic position or gender.

This thesis demonstrates that socioeconomic differences exist in the intensity patterning of children's physical activity behaviour with no evidence that current promotion efforts are propagating inequalities. The international focus on the aggregate of moderate-to-vigorous physical activity may be masking meaningful inequalities between socioeconomic groups of children. Further research is needed to determine the most appropriate daily dose of vigorous

activity and to develop interventions that provide opportunities for less socioeconomically affluent children to engage in physical activity of a sufficient intensity to maximize health benefits. All physical activity promotion research should focus on the assessment and maximization of intervention fidelity.

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List of Abbreviations and Acronyms

$	US Dollar
%	Percentage
***	Indicates significance (p<0.05)
**	Indicates significance (p<0.01)
*	Indicates significance (p<0.001)
£	GB Pound
<	Less then
>	Greater then
≤	Less then or equal to
≥	Greater then or equal to
A2-A6	Appendix 2 – Appendix 6
BMI	Body Mass Index
BT20	Birth to Twenty Cohort
CI	Confidence Interval
cm	centimetres
E.g.	Exempli gratia or ‘for example’
I.e.	Id est or ‘That is’
IQR	Interquartile change
kg	Kilogram
LPA	Light physical activity
m	Metre

MCS	Millennium Cohort Study
METS	Metabolic equivalent of task
Mins	Minutes
MPA	Moderate physical activity
MVPA	Moderate-to-vigorous physical activity
N	Number (used to indicate number of participants in a study)
NCDs	Noncommunicable diseases
NHS	National Health Service
OR	Odds Ratio
p	p-value
RCT	Randomized controlled trial
SD	Standard deviation
SEP	Socioeconomic position
SMD	Standardized mean difference
UK	United Kingdom

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1 BACKGROUND

Health is unequally distributed across society. Socioeconomic gradients in health outcomes are present at every stage of the life course.[1] Accordingly, socioeconomically disadvantaged populations fare worse with regards to noncommunicable disease risk prevalence and correspondingly disability-free life years and life expectancy.[2,3]

Evidence reveals that physical activity behaviour is a central contributor to the development of a range of socioeconomic inequalities in health including the stark, graded differences in obesity prevalent across adult populations.[4,5] Despite rising socioeconomic inequalities in childhood obesity, there is limited understanding of the contribution of behavioural risk factors to these inequalities, including the contribution of differences in physical activity.

It is also unclear if current efforts to promote physical activity are equally effective within populations of children. It is possible that intervention efforts inadvertently increase inequalities, through providing greater benefit to advantaged than to disadvantaged groups.[6]

The research included in this dissertation contributes to filling these gaps in the evidence through investigating existing inequalities in children's physical activity behaviour and their response to interventions to increase physical activity. In this introduction, I provide the background needed to meet these aims.

1.1 Noncommunicable diseases and obesity

1.1.1 Noncommunicable diseases

Noncommunicable diseases (NCDs) are the leading cause of preventable morbidity and mortality globally.[7] The escalating burden of NCDs has been named by the United Nations as one of the central challenges for development in the twenty-first century in consideration of its role undermining worldwide social and economic development.[8] NCDs – predominantly cardiovascular disease, cancer, chronic respiratory disease and diabetes – account for over 70% of global deaths, of which nearly half are in individuals younger than 60 years of age.[7] While NCDs affect most countries worldwide a disproportionate and rising burden is in low-and-middle-income countries (LMICs) where 80% of premature deaths from NCDs occur.[9,10]

The growing NCD crisis has drastic consequences for health care, as well as high social and economic costs for all countries globally. The economic cost of continued underinvestment in the fight against NCDs is estimated at a global loss of $47 trillion in gross domestic product annually.[11] Projections to 2040 demonstrate rapid rises in years of life lost from NCDs if 'business as usual' continues.[12] While cost-benefit analyses demonstrate a high return on investment for NCD prevention, for countries at all income levels, action and progress has been slow.[13]

1.1.2 Obesity

Increasing rates of overweight and obesity globally are major drivers of the NCD pandemic.[14] Large scale and long-term prospective studies indicate that both overweight and obesity are associated with both NCDs and higher all-cause mortality, with consistent associations across continents globally. A high body mass index (BMI: weight in kilograms divided by the square of height in metres) is specifically with multiple NCDs including cardiovascular disease, diabetes mellitus, chronic kidney disease and many cancers.[15–18]

While levels and trends in overweight and obesity show distinct regional patterns, a general increase is observed globally.[14] No country has seen significant decreases in obesity between 1980-2013. The escalating burden of rising BMI rates across populations has led to its inclusion as a central target in the World Health Organisation's *Global Action Plan for the Prevention and Control of Noncommunicable Diseases 2013-2020,* which sets a worldwide goal of halting the rise in the prevalence of obesity at its 2010 level.[19] While recent pooled analyses conclude that the probability of meeting this target is virtually zero, there is a clear need to develop interventions and policies that effectively stop rising rates.[20]

While the overall global prevalence of obesity in children is lower than in adults, the rate of increases in childhood obesity are comparatively greater in many countries worldwide.[20] Global prevalence of overweight and obesity in children has increased tenfold over the past four decades.[14,21] As demonstrated in Figure 1.1, prevalence of childhood obesity has risen drastically from 1980 across all contexts globally, with varying rates of increase by national level of development and gender. Given that childhood obesity is strongly correlated with obesity, physical morbidity and premature mortality in adulthood, there is a evident need to focus efforts early in the life course.[22]

Tracking obesity across the lifespan, the costs to public spending are enormous and continuing to rise. In the UK alone, the economic costs of obesity are valued to be £20 billion annually.[23] The lifetime healthcare and productivity costs of childhood obesity are estimated to be £129,604, per child.[24] Parallels have been drawn between the mounting burden and a slow-moving car crash with regards to the effects of childhood obesity, associated diseases and rising healthcare costs. Without significant investment in prevention the sustainability of healthcare systems and economic prosperity of societies globally will increasingly be at risk.

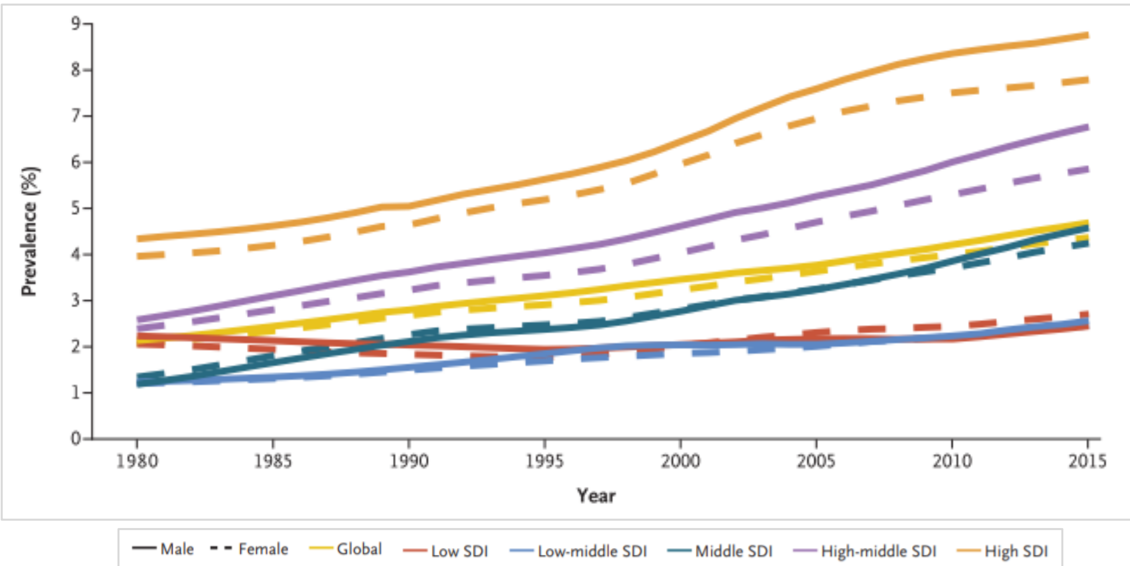


Figure 1.1 Prevalence of childhood obesity globally (age-standardized), by quintiles of Sociodemographic Index (SDI), from 1980 to 2015 [350]

1.1.3 Risk factors

The rising global prevalence of morbidity and mortality from obesity and NCDs is largely preventable through four modifiable risk factors: physical inactivity, unhealthy nutrition, tobacco use and the harmful use of alcohol. These four behavioural risk factors lead to overweight and obesity, raised blood pressure and cholesterol, and eventually the onset of NCDs.[7]

This thesis focuses on the behavioural risk factor of physical activity. However, this focus is under the recognition that obesity and NCDs are complex problems that will not be addressed by a singular behavioural focus.

1.2 Physical activity

1.2.1 Physical inactivity

Physical inactivity is the fourth leading risk factor for global mortality.[25] Worldwide, 31% of adults are physically inactive, which is estimated to have caused 5.3 million of the 57 million global deaths in 2016. This accounts for 9% of premature mortality and 6-10% of all deaths from major NCDs.[25] It is estimated that an increase in physical activity by only 10% would prevent half a million deaths every year.[26]

All populations globally would benefit from increases in physical activity. A recent analysis of 130,000 individuals revealed across 17 high, middle and low income countries higher levels of physical activity are consistently associated with a lower risk of cardiovascular disease and mortality.[27] Alongside physical inactivity being an independent risk factor for cardiovascular disease, it further compounds mortality risk through its association with obesity.[28]

Increasing physical activity offers a simple and low-cost strategy of tackling rising rates of both obesity and chronic disease globally.[29] Encouragingly, improvements to population levels of physical activity have been identified as a top public health priority both in the Sustainable Development Goals and the World Health Organisation's global action plan which calls for a 10% relative reduction in the prevalence of insufficient physical activity worldwide by 2030.[30] This international focus has led to a rise in the adoption of national policies and increased recognition of the promotion of physical activity as a key element of efforts to improve the health of populations.[31]

1.2.2 Defining physical activity

Caspersen et al. (1985) defined physical activity as *'any bodily movement produced by skeletal muscles that results in energy expenditure'*.[32] While extensively accepted across the field, a more recent conception and definition has been developed which defines physical activity as '*behaviour that involves human movement, resulting in physiological attributes including increased energy expenditure and physical fitness'*.[33] These definitions capture *movement* that is both structured (e.g. organised repetitive activity) and unstructured (e.g. unsupervised play).[34] The total amount of activity captured is comprised and can be categorized according to their frequencies (the number of physical activity bouts within a specific period), the duration (the time of participation in a bout of physical activity), the intensity (the physiological effort involved in carrying out physical activity and often quantified in multiples of resting metabolic rate) and the type or mode of the activity (what activity is being carried out).[35]

Energy expenditure is frequently expressed in multiples of resting energy expenditure, commonly understood as Metabolic Equivalent Tasks (MET). One MET is equal to the resting energy cost of 1 kcal/kg/hour. Based on the MET cost, physical activities are classified as light, moderate or vigorous. Sedentary behaviour is defined as any waking behaviour characterized by an energy expenditure ≤1.5 METs, while in a sitting, reclining or lying posture.[36] Table 1.1 below outlines each category of physical activity with their associated MET values and associated activity examples. The activity examples are drawn from the recently updated youth compendium of physical activities which standardises outcomes and estimates the energy costs of physical activities for children and youth.[37] The compendium consists of MET values for 196 specific activities classified into 16 major categories for four age groups: 6-9, 10-12, 13-15 and 16-18 years.

Table 1.1 Physical activity intensity categories, associated MET values and activities [37]

Intensity category	**MET Value**	**Example activities**
Sedentary	1-1.4	Reading, writing, watching TV
Light (LPA)	1.5-2.9	Standing, slow walking
Moderate (MPA)	3.0-5.9	Walking, playing with balls, strength exercises
Vigorous (VPA)	≥6.0	Running, jumping rope, playing soccer

1.2.3 Physical activity guidelines

The World Health Organization (WHO) recommends children accumulate 'at least 60 mins moderate-to-vigorous intensity physical activity (MVPA) daily'.[38] The guidelines additionally recommend that vigorous activities are incorporated three times a week. The WHO upholds that this recommendation is applicable irrespective of equity factors including the socioeconomic circumstances of individuals.

Most countries worldwide adopt the WHO's set MVPA target; however, some will make different recommendations on how to achieve the targets. For example, the UK's Chief Medical Officer and National Obesity Action Plan,[39] adopts the WHO target recommending at least 60 minutes of physical activity for children every day, with the Department of Health and Social Care suggesting that half of these minutes be delivered in school settings.[40] Given the central focus of international recommendations on the accumulation of MVPA, most research, national surveys and intervention trials utilize MVPA to quantify and study activity levels.

1.2.4 Measuring physical activity

Physical activity is a complex behaviour that is challenging to measure. Valid and reliable measurements of physical activity are required to document the frequency, duration and distribution of physical activity in populations, evaluate the proportion of individuals meeting set guidelines, examine the effects of different activities on health and evaluate the effects of interventions.[41]

Physical activity assessment can be divided into three major categories: subjective report-based measures (e.g. questionnaires, diaries, activity logs), objective monitor-based measures (e.g. accelerometers, pedometers, heart rate monitors) and criterion measures (doubly-labelled water, indirect calorimetry). Each method of measurement varies in its validity, cost, feasibility, duration, and the burden for the investigator and participant.[35]

It is suggested that there is a negative relationship between the feasibility/accuracy and the precision of a measurement method.[41] Measures that are highly valid (e.g. criterion measures) are too expensive to use in large-scale research applications, while more feasible measures (e.g. questionnaires) have lower validity. The advantages and limitations of central methods of physical activity measurement are outlined in Table 1.2 and described in the sections below.

1.2.4.1 Report-based measurement

Subjective report-based measurement methods including activity diaries and questionnaires are designed to collect subjective information about multiple dimensions of physical activity which is then used to estimate the time spent across different activity intensities.[42] Subjective measures are often used to assess physical activity in large populations of children as they are the most feasible, low-cost and easy to administer.

The use of subjective report-based measures should however be considered carefully as they are highly susceptible to measurement error. Bias is often introduced due to misreporting, both deliberately due to social desirability bias and unintentionally due to limitations with recall. Subjective measures are particularly limited in accuracy in infants and young children who are at an earlier stage of cognitive development and have limited ability to recall behaviour.[43] To overcome this barrier, proxy reporting through either parental or teacher reports are commonly used. However, both have been shown to have limited validity, so should be used with caution.[44]

Table 1.2 Advantages and limitations of physical activity assessment tools [44–46]

Method	Advantages	Limitations
Report based measures		
Self-report questionnaires & diaries	- Easy to administer - Low-cost enabling their use in large studies - Low burden to participants - Provide information on patterns, types and contexts of activities	- Low accuracy and reliability - Dependent on memory and thus reduced validity in children younger than 10 due to cognitive limitations in recall - Parental proxy is inaccurate for estimating the amount and intensity of physical activity (can be helpful for rank ordering children) - Susceptible to measurement bias due to social desirability bias and misreporting
Monitor -based measures		
Accelerometers	- Provides objective measurement of physical activity including an estimation of the intensity and duration of movement - Relationship between accelerometer counts and energy cost allows physical activity to be classified by intensity - Reduces recall and researcher bias - Non-invasive and less burdensome to participants - Can be used both in controlled and free-living settings - Able to record data continuously over an extended period	- High research cost - Places high burden on researchers - Does not provide information on the contexts or type of activities - Does not capture certain activities including cycling and swimming - Comparison between studies is hindered by differing accelerometer brands, cut-points and thresholds between studies - Continuous wear over extended period may be burdensome to child - Low sensitivity to sedentary activities and inability to register static exercise
Heart rate monitors	- Collects continuous readings of heart rate - Greater individual accuracy through individual calibration of the monitor - Non-invasive and inexpensive	- Provides an indirect measure of physical movement - Inaccurate in measuring sedentary and high intensity activities - High researcher burden in calibrating individual monitors to participants - Heart rate, and thus accuracy of measurement, is influenced by external factors unrelated to the activity being measured including stress, dehydration and climate

Pedometers	- Provides objective measurement of ambulatory activity - Easy for participants to use - Not obtrusive to participants - Output is easy to interpret and can be used in participant engagement and motivation - Inexpensive and non-invasive	- Measurement is sensitive to the position of the wear - Fail to account for individual differences in height and leg length - Step count is influenced by stride length and speed of walking which can lead to an under- or over-estimation of steps - Wide variation in validity and reliability between monitors - Only measures cumulative physical activity with respect to walking - Inaccurate for assessing distance covered and energy expended - Most are limited in their ability to time-stamp data
Criterion measures		
Doubly-labelled water	- Highly accurate and precise, - Is considered the gold standard for measurement of total energy expenditure - Applicable in a wide range of populations, including infants	- Extremely high research cost - High amounts of expertise and training required for personnel - Does not quantify activity type, intensity or duration
Indirect calorimetry	- Accurate and non-invasive - Enables the assessment of energy expenditure in the field	- Relatively high cost - Requirement for trained personnel - Involves expensive equipment
Direct observation	- Provides detailed contextual information - Not obtrusive to participants	- Presence of observer may influence participant’s behaviour - Training of observer is expensive and time consuming - Captures only one segment of activity across the day

Additionally, evidence indicates that due to the design of self-report questionnaires they more accurately measure organised activities and are less robust in capturing light or moderate activity.[47] Given that participation in organised activities differs between sociodemographic groups this dimension has the potential to introduce a further bias.[48]

1.2.4.2 Monitor-based measurement

Objective monitor-based measures, including heart-rate monitors, accelerometers and pedometers, provide considerably greater precision and accuracy than subjective self-report measures.

Through measurement of the physiological response to movement, heart rate monitors capture the level of stress imposed on the cardiovascular system. Heart rate thresholds are then used to determine the amount or percentage of time that children spend above pre-defined intensity levels. Heart rate monitors are centrally limited in their ability to capture low intensity activity and intermittent activity, which has the potential to introduce measurement error given the substantial amount of time spent by children in sedentary and light physical activity across the day, alongside children's characteristically intermittent activity patterns.[49] The accuracy of readings is also influenced by external factors that influence the heart rate irrespective of movement (these factors include temperature, level of hydration, caffeine, stress, anxiety). While heart rate monitors are advantageous in being relatively inexpensive and unobtrusive, they are limited in application within physical activity research centrally due to a lack of specificity.[45]

These limitations in the specificity of measurement are overcome by accelerometers. Accelerometers have been shown to be reliable and valid in comparison to measures of physical activity derived from heart rate monitoring, indirect and room calorimetry, and doubly labelled water.[50–52] Accelerometers provide an objective measure of the amount of activity being performed, often called a 'activity count', which is subsequently transformed to meaningful outcomes (energy expenditure and METs). By considering individual level information, behaviour can be categorized into intensity levels of physical activity (sedentary, light, moderate and vigorous) across the child's day.

The use of accelerometers is commonly restricted by the high price of monitors. Accelerometers are additionally limited by an inability to provide information about the context or type of activities, an underestimation of activity involving vertical movement such as cycling (if worn on the waist) and can also not be worn for certain activities, including swimming and contact sports.

Comparison of accelerometer data across studies is made difficult by the use of differing accelerometer cut points and thresholds between studies.[53] These data processing decisions can generate significant differences in physical activity estimates which makes comparing study results in unharmonized datasets difficult. Additionally, due to substantial intra-individual (within subject) variation, the number of days of assessment that is required to obtain an estimate of physical activity, influences what constitutes a 'reliable' estimate and drives differences across studies.[54]

Despite these limitations, accelerometers offer many advantages through their ability to accurately and precisely estimate physical activity across populations of children and adolescents. Their use and the objective measurement of physical activity is particularly important when comparing equity subgroups, such as children from varying levels of socioeconomic position,[55] as self-reported data has been shown to be differentially biased across different subgroups.[56] While it is possible that the activities accelerometers cannot measure (e.g. cycling) are differentially patterned between subgroups of children this can be deemed a lesser threat to validity of measurements compared to self-report methods.

Pedometers measure the number of steps taken over a given period through vertical motion when a child's hip accelerates. Due to the simplicity of pedometers they are a comparatively low-cost alternative to both heart rate monitors and accelerometers. While measurement is limited to vertical motion (movement across other planes is not recorded), they have been shown to be valid at measuring overall physical activity levels across populations.[57] However, because pedometers only collect counts or steps across a measurement period, they are centrally limited by their inability to assess the intensity or pattern of the activities measured. Lastly, most pedometers are limited in their ability to timestamp data and accordingly understand when across a day activity was performed.

1.2.4.3 Criterion measurement

Doubly labelled water, indirect calorimetry and direct observation provide criterion estimates of energy expenditure and movement. These measures are typically used for validation studies or small lab-based study designs where precise indicators are needed.[34]

Doubly-labelled water provides the most accurate measure of total-energy expenditure and accordingly is widely held as the gold standard. It measures energy consumption based on the estimation of carbon dioxide elimination from the body. This is done through the administration of isotope labelled water and tracing of the elimination of isotopes in urine samples over time. Given the high price and the high level of required training to conduct studies with doubly labelled water, alongside the high participant burden, its use is limited to when precise estimates are required.

Indirect calorimetry provides an estimate of energy expenditure through the measurement of oxygen consumed and carbon dioxide produced (referred to as the respiratory exchange ratio).[34] It is frequently used to establish relationships between movement and estimates of energy expenditure from monitor-based tools.[58] Methods of indirect calorimetry are most commonly used to quantify energy expenditure in both laboratory and field settings through the use of portable gas exchange and analysis systems.

Lastly, direct observation involves watching participants to classify the type, intensity, duration, frequency and context of activities performed. Classification is made through the assessment of behaviours, postures, associated activity intensities (e.g. sedentary, light, moderate, vigorous) and the time spent in each. Direct observation instruments (e.g. System for Observing Fitness Instruction: SOFIT) are used which set standardized procedures and require the use of trained observers.[59] While the application of standardised instruments demonstrate good objectivity despite the degree of subjectivity involved, there is a high experiment burden due to the costs, personnel and time required.[34]

1.2.5 The benefits of physical activity in children

The benefits of engaging in regular physical activity during childhood are well established: physical activity plays a central role in promoting health and well-being and reducing future disease risk.[60,61] Current evidence and understanding across three key categories of benefits (cardiometabolic risk factors, adiposity and psychological well-being, cognitive functioning and academic performance) are summarised below.

1.2.5.1 Cardiometabolic risk factors

Many analyses and reviews have examined the prospective associations between children's physical activity and cardiometabolic outcomes.[62–65] Numerous studies conclude that children's overall physical activity is associated with reduced overall cardiometabolic risk, with differences in benefit across specific risk factors. The most up to date review and meta-analysis by Skrede et al. (2018),[66] which aggregated the findings of 30 prospective studies (of which 21 were deemed to be of high quality) revealed a small but significant, inverse, relationship between MVPA and the clustering of cardiometabolic risk factors in youth.[61] There was no evidence of an association between sedentary time and cardiometabolic outcomes.[61] The associations between objectively measured MVPA and individual cardiovascular risk factors (including body mass index, waist circumference, triglycerides, high-density lipoproteins, insulin and blood pressure) were inconsistent.[61] These findings are strengthened by the review's restriction of evidence to longitudinal, observational prospective cohorts, randomized controlled trials and intervention study designs. Regardless of the amount of time children spend sedentary, higher levels of MPVA are associated with better cardiometabolic risk factors. This is a dose response relationship in which more physical activity leads to greater benefit.[61]

1.2.5.2 Adiposity

While some studies demonstrate an association between MVPA in childhood and reduced adiposity,[67,68] others indicate a less clear relationship.[69] A recent review illustrated when restricted to higher quality study designs, the prospective association between MVPA and adiposity is inconsistent.[66] One explanation is the proposal of reverse causality where obesity causes a child to be less active rather than a child becomes obese because they are less active. Obese children, compared to their counterparts, exhibit significantly lower daily accumulations of total counts and MVPA.[70] Physical activity and overweight and obesity show moderate tracking over time.[71–73]

While overall evidence for the relationship between MVPA and adiposity continues to be inconsistent there are established differences in adiposity benefits by activity intensity. A substantial amount of evidence exists demonstrating that higher intensity activity within the vigorous intensity spectrum is associated with reduced waist circumference and adiposity relative to lower intensity activity.[74–78] Strong evidence reveals that higher intensity physical activity (VPA) is more strongly associated with lower levels of adiposity then lower intensity activity (MPA).[79–82] The benefits operate independently and in addition to the energy expenditure dose of VPA, with evidence of a long-term protective effect in children.[81]

1.2.5.3 Psychological well-being, cognitive functioning and academic performance

Given rising mental health problems in young people globally there has been a substantial, and increasing, amount of research on the relationship between physical activity and depression, self-esteem and cognitive functioning. A recent review of reviews demonstrated partial support for a causal link between physical activity and depression in young people.[83] It also illustrated that some evidence exists for anxiety reduction effects from physical activity alongside inconclusive findings regarding the effect of physical activity on self-esteem.

In the time since the publication of Biddle et al's (2011)[84] review of reviews, and their update (2018)[83], a further 25 systematic reviews, representing a 3.6-fold increase, were identified for inclusion regarding the effect of physical activity on cognitive functioning demonstrating growing interest on the topic. This recent review revealed a small but positive effect for the impact of physical activity on cognitive functioning, which included both cross-sectional and longitudinal analyses. There was no evidence of a dose-response across any of the outcomes. Other reviews have illustrated no effect on cognitive functioning.[85]

The most recent collation of evidence on the effect of physical activity on academic achievement by Singh et al. (2018) revealed inconclusive evidence for overall academic performance, but strong evidence for the beneficial effects of physical activity on maths performance.[85]

1.2.6 The descriptive epidemiology of children's physical activity behaviour

The proportion of children and adolescents meeting international guidelines depends on the assessment method and successive processing and interpretation of the data. However, most analyses indicate that only a small proportion of children currently meet international recommendations.[86] The prevalence of sufficient physical activity in adolescents is similarly low. International surveillance data from 105 countries demonstrate that 80% of 13-15 year olds do not achieve the global recommendation of 60 minutes of MVPA per day (See Figure 1.2).[87] These figures illustrate that overall girls are much less active than boys. Given that the majority of national and international physical activity surveillance data is collected through surveys with questionnaires, it is accordingly susceptible to measurement error and bias, likely underestimating rates of physical inactivity.[56]

The International Children's Accelerometery Database (ICAD) is the largest harmonised dataset of accelerometer-assessed activity and includes 20 studies worldwide. Analyses of ICAD support the concerning overall figures of inactivity and confirm the observed gender differences.[80] Boys (mean age 11.3) spend an average of 37 minutes engaged in MVPA while girls engage in only 24 minutes, (65% that of boys) per day.

There is no clear pattern for children's physical activity between regions and countries across the world. Objective physical activity studies involving only European countries (across 4 countries)[88] and ICAD[89] (includes 20 studies across 10 countries) suggest that no clear trends exist between countries, while some other multi-region studies indicate the presence of meaningful differences.[90]

The association between children's socioeconomic position and level of MVPA is similarly inconclusive. Some findings suggest less affluent children accumulate less overall MVPA while other recent reviews conclude no effect.[91,92] The majority of included research using objectively measured physical activity illustrate no apparent socioeconomic patterning in children's adherence to international guidelines.

There is evidence that ethnic and cultural factors influence children's activity levels within country settings. For example within the UK, multiple studies have revealed South Asian children (individuals who identify as Indian, Pakistani or Bangladeshi) have significantly lower objectively measured physical activity than their white European counterparts.[93–95] Lower levels of activity in certain ethnic minority groups is shown to be driven by a range of factors including cultural and religious influences, lack of access to organised sport and parental safety concerns.[96]

Activity levels have been shown to significantly decline during the transition from childhood into adolescence for all subgroups.[72,97] Considering evidence demonstrating that activity levels track throughout the lifespan into adulthood,[71,98] children with low levels of physical activity are at risk of being inactive later in life and suffering from increased morbidity and mortality.[73,99] A recent analysis illustrated that decreases in physical activity are more pronounced in socioeconomically-deprived and non-white children,[100] although the mechanism driving these declines are not fully known.

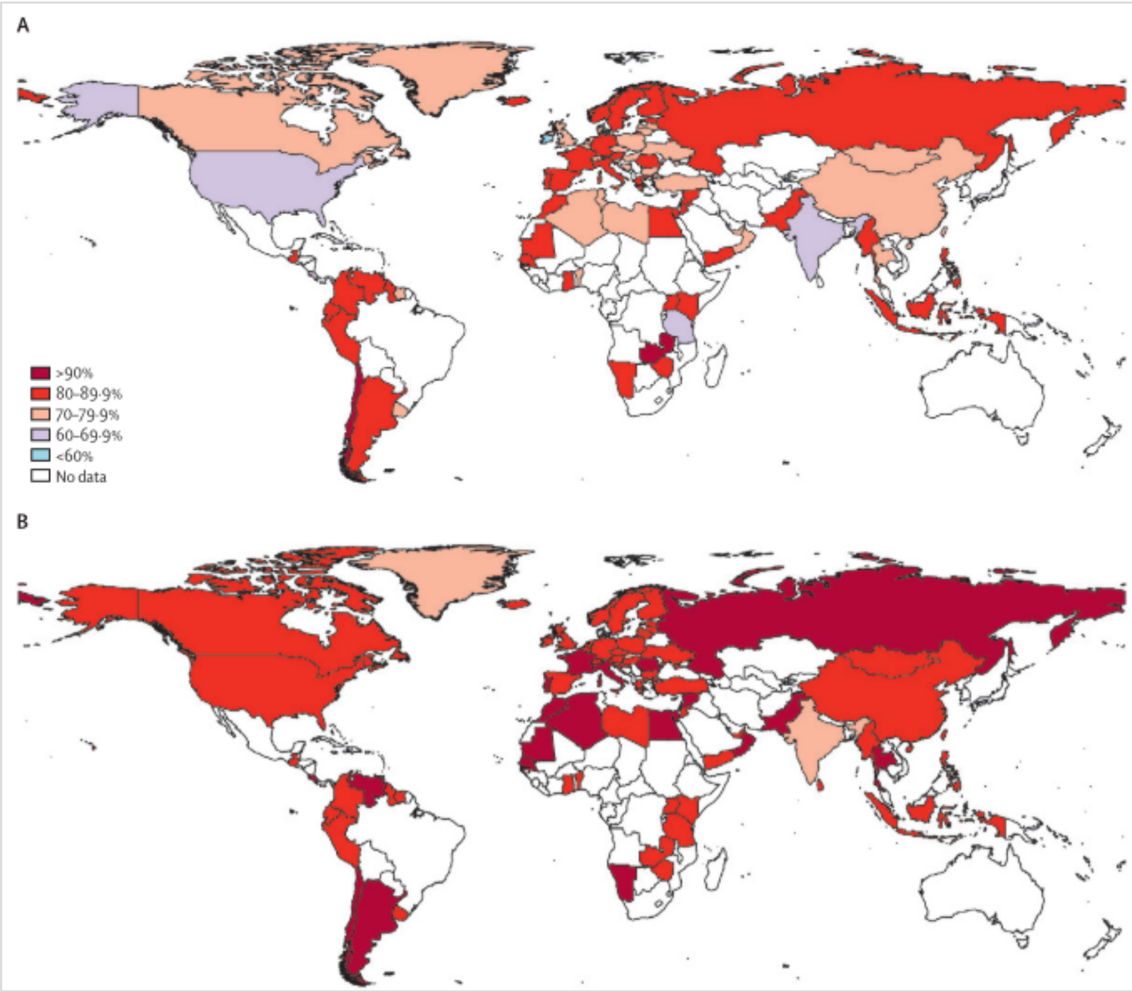


Figure 1.2 Proportion of 13-15-year-old A) boys and B) girls not achieving 60 minutes of moderate-vigorous of physical activity per day [87]

1.2.7 Physical activity promotion

1.2.7.1 Approaches to physical activity promotion

Geoffrey Rose's seminal paper, *Sick individuals and sick populations,* proposed two categories of approaches to prevention of disease.[101] 'High risk strategies' target interventions at individuals designated with a higher risk of developing the disease (See Figure 1.3), whereas 'population strategies of prevention' target entire populations and work to improve health by shifting the entire distribution of underlying risk factors (Figure 1.4).

High risk strategies to prevention are implemented to decrease behaviour risk factors and disease outcomes among those with the greatest potential burden. A general limitation of high risk approaches is the difficulty and cost involved in continuous and expensive screening processes to identify high-risk individuals.[102] In contrast, population strategies seek to lower overall risk or behaviour across an entire population. Commonly, there is a trade-off between equity and efficiency due to scarce resources. Population approaches often have limited effect on individuals but overall gains when summed across the entirety of the population. There also are times when population strategies may inadvertently worsen health inequalities within a population.[103]

Parallels are drawn between what Rose called 'underlying causes' and others call 'social determinants of health': these underlying causes involve resources such as the knowledge, money, power and prestige that enable people or groups to avoid risk and adopt protective strategies.[103,104] The absence of these resources is often seen in individuals and groups of lower socioeconomic standing. Addressing these differences and effectively promoting health across the entirety of a population is suggested to require strategies which combine universal population strategies alongside targeted high risk measures that offer extra support to those with the greatest disadvantage and need.[105]

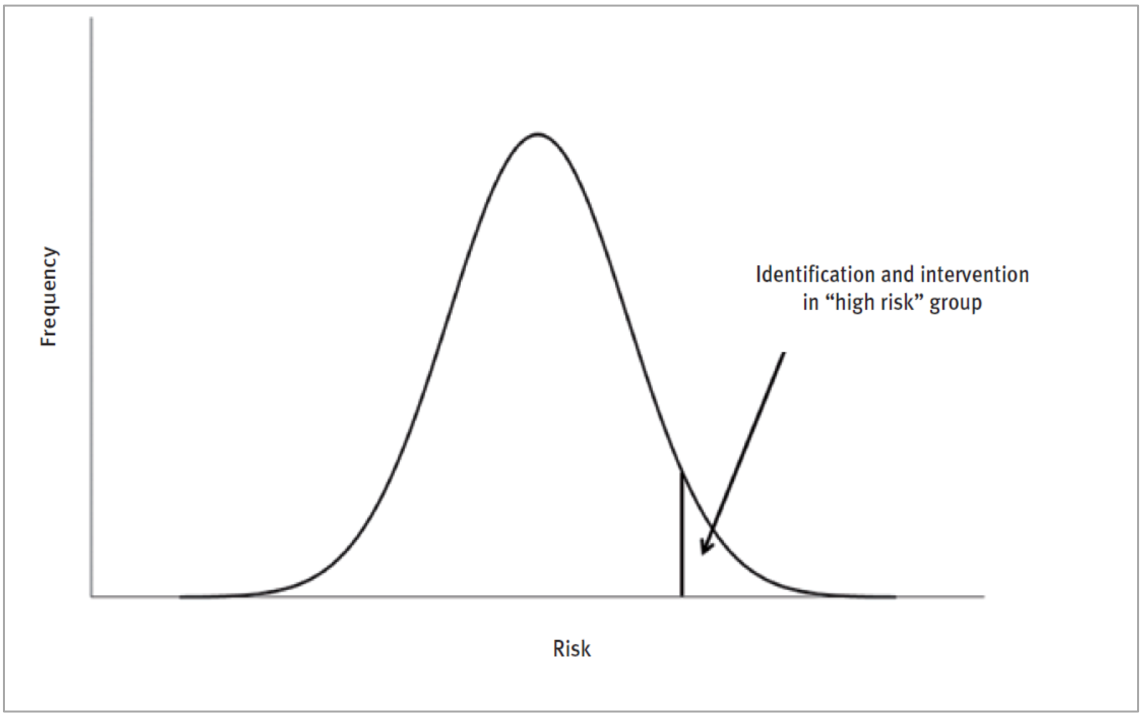


Figure 1.3 High-risk approach to public health interventions [351]

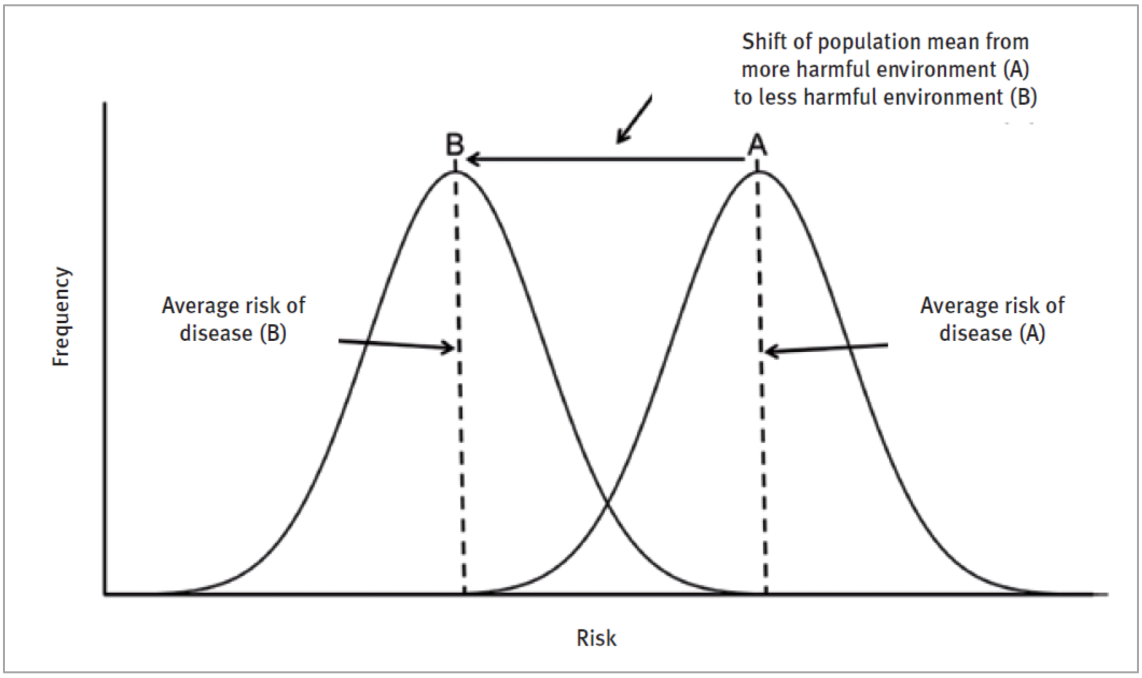


Figure 1.4 Population approach to public health interventions [351]

1.2.7.2 Physical activity promotion in children

The development of both universal and targeted interventions to increase physical activity in children has been identified by governments and public health agencies as a key research priority for promoting health equity and improving population health outcomes.[31,106] A multitude of children's physical activity interventions across home, school and community settings have been developed. However, the effectiveness of these interventions has been mixed.[107–110] Many systematic reviews have evaluated the effectiveness of accumulating intervention evidence in child and adolescent populations. A set of central reviews from the field summarising evidence on children's physical activity promotion are outlined in Table 1.3. While early reviews concluded the existence of strong evidence that interventions could effectively increase physical activity behaviour, there is an apparent trend as measurement methodologies and inclusion criteria develop to be more robust that conclusions become increasingly less significant.

Given the promise of schools as a universal context to access and influence all children, irrespective of socioeconomic position, a central focus of intervention efforts is on population approaches to intervention within the school setting. The emphasis on school-contexts in efforts to improve health is reflected in both national and global guidelines. The WHO's Best Buys for NCDs makes recommendations to countries based on the most up to date evidence of effective interventions.[111] The central recommendation for physical activity specific to children outlines *'Implement whole-of-school programmes that include quality physical education alongside the availability of adequate facilitates and programs to support physical activity for all children'*. Similarly, the UK's Chief Medical Officer,[39] recommends that children engage in at least 60 minutes of physical activity every day, with the accompanying suggestion that half of these minutes be delivered in school settings.[40] Considering this focus across national and international guidance a large amount of intervention efforts for children's physical activity, target school-based contexts through population approaches.

Table 1.3 Summary of systematic reviews of children's physical activity interventions

Review details and objective	Inclusion criteria and methods	Studies included, main effect and findings [1]
Van Sluijs et al (2007). *BMJ.* [112] Effect of interventions to promote physical actiivty in children and adolescents: a systematic review of controlled trials. **Objective:** To review the published literature on the effectivness of interventions to promote physical activity in children and adolescents.	**Inclusion Criteria:** - **Design:** Controlled trial, comparison of intervention to promote physical activity with no intervention control condition. - **Participants:** Participants younger than 18 years. - **Outcome:** Reported statistical analyses of a physical activity outcome measure. **Methods:** Systematic literature review, assessment of methodological quality and data extraction.	**Studies included:** 57 studies (33 in children, 24 in adolescents). **Main effect:** Some evidence was found for potentially effective strategies to increase children's levels of physical activity. Strong evidence was found that school-based interventions with involvement of the family or community and multicomponent interventions can increase physical activity in adolescents. **(++)** - A lack of high-quality evaluations hampers conclusions concerning effectiveness, especially among children. Among children, limited evidence for an effect was found for interventions targeting children from low socioeconomic populations, and environmental interventions.
Van Sluijs et al. (2011). *Br J Sport Med*.[113] The effect of community and family interventions on young people' s physical activity levels: a review of reviews and updated systematic review. **Objective:** To explore the effectiveness of interventions to promote physical activity in children and adolescents, delivered in the family and community setting, summarise previous	**Inclusion Criteria:** - **Design:** Controlled trials with a no physical activity control condition. - **Participants:** Children and adolescents less the 18 years of age. - **Intervention:** Promotion of physical activity through behaviour change as the main intervention component in family and community settings.	**Studies included:** 13 family and 3 community-based interventions (pooled from three reviews). **Main effect:** Significant positive effects on physical activity were observed for one community-based and three family-based studies. **(++)** - No distinctive characteristics of the effective interventions compared to those that were ineffective were identified.

Review details and objective	Inclusion criteria and methods	Studies included, main effect and findings [1]
reviews and update the evidence with findings from recently conducted controlled trials.	- **Outcome:** Statistical analyses of a physical activity outcome measure. **Methods:** Review of reviews, quality assessment, extraction of methods and intervention effects.	The effect of family- and community-based interventions remains uncertain despite improvements in study quality. Of the little evidence of effectiveness, most comes from those targeted at families and set in the home.
Kriemler et al. (2011). *Br J Sports Med.* [114] Effect of School-Based Interventions on Physical Activity and Fitness in Children and Adolescents: A review of reviews and systematic update. **Objective:** To 1) summarize recent reviews of studies with the aim of increasing physical activity or fitness in children and adolescents, 2) to define, based on these reviews, potentially relevant factors for a positive outcome, and 3) to carry out a systematic review of new intervention studies and prospectively verify the predefined factors.	**Inclusion Criteria:** - **Design:** Controlled and randomized controlled trials. - **Interventions:** Trials aimed at increasing physical activity or fitness, at least 12 weeks in duration. - **Outcome:** Physical activity or fitness outcome measure at baseline and one follow-up (both objective and subjective measurements were included). - **Participants:** Healthy school-aged children and adolescents aged 6-18 years. **Methods:** Systematic literature review, assessment of methodological quality and data extraction.	**Studies included:** 20 trials were included in the review. **Main effect:** All 20 trials fulfilling the inclusion criteria in the review update showed a positive effect on in-school, out-of-school or overall physical activity, and 6 of 11 studies showed an increase in fitness. **(++)** - Taking into consideration both assessment quality and public health relevance, multicomponent approaches in children including family components showed the highest level of evidence for increasing overall physical activity.
Metcalf et al. (2012). *BMJ.* [115] Effectiveness of intervention on physical activity of children: systematic review and meta-analysis of controlled trials with objectively measured outcomes (EarlyBird 54) **Objective:** To determine whether, and to what extent, physical activity interventions affect the overall activity levels of children.	**Inclusion criteria:** - **Design:** Randomised controlled trials or controlled clinical trials (cluster and individual), published in peer reviewed journals. - **Intervention**: Incorporated a component designed to increase the physical activity of children/adolescents and was at least four weeks in duration. - **Outcomes:** Measured whole day physical activity objectively with accelerometers either before or	**Studies included:** 30 interventions. **Main effect:** The pooled intervention effect across all studies was small to negligible for total physical activity (standardised mean difference: 0.12, 95% confidence interval 0.04 to 0.20; P<0.01). Small effect for MVPA (0.16, 0.08 to 0.24; P<0.001). **(+)** - Meta-regression indicated that the pooled intervention effect did not differ significantly

Review details and objective	Inclusion criteria and methods	Studies included, main effect and findings [1]
	immediately after the end of the intervention period. **Methods:** Systematic review, meta-analysis and series of meta-regressions.	between any of the subgroups (by age [in less than 10 or greater than 10 age range], body mass index [across the entire range and for overweight/obese], study duration [≤6 months and >6 months], home/family vs school, low vs high quality studies).
Sims et al (2014). *Plos One.* [116] Effectivness of interventions on sustained childhood physical activity: a systematic review and meta-analysis of controlled studies. **Objective:** The primary objective was to conduct a systematic review to explore the effect of interventions on maintained whole-day childhood physical activity, including studies that measured physical activity level with either accelerometers or questionnaire. The secondary objective was to explore sustained effect sizes at least six months post-intervention.	**Inclusion criteria:** - **Design:** Controlled studies with a non-physical activity control group. - **Intervention:** Any intervention targeting physical activity levels. - **Participants:** Children and adolescents aged 5 to 18 years. - **Outcome:** Measure of MVPA or total physical activity spanning at least two domains of physical activity obtained either by objective measurement or validated self-report measure with a follow-up measure at least six months post-intervention. **Method:** systematic review, meta-analysis and series of meta-regressions.	**Studies included:** 14 studies included **Main effect:** Negligible mean difference in MVPA existed in favour of the intervention group, amounting to [standardized mean difference] 1.47 (95% CI: -1.88 to 4.82) mins/day compared to controls. No difference on Total Physical Activity. **(+)** - Males (2.65 mins/day: 2.03 to 3.27) reported higher levels of MVPA than females (-0.42 mins/day: -7.77 to 6.94). - Community settings (2.67 mins/day: 2.05 to 3.28) were more effective than school settings. - Targeted treatment (4.47 mins/day: -0.81 to 9.76) demonstrated greater effects than population approaches (1.03 mins/day: -2.54 to 4.60).
Dobbins et al. (2013). *Cochrane Collaboration Reviews.* [110] Cochrane Collaboration Review. School-based physical activity programs for promoting physical activity and fitness in children and adolescents aged 6 to 18 (Review).	**Inclusion criteria:** - **Design:** Randomised controlled trials - **Intervention:** Intervention had to focus on health promotion activities, be implemented in a school setting and aimed at increasing physical activity, included all school-attending children, and be at least 12 weeks in duration.	**Studies included:** 44 studies were included **Main effect:** Some evidence to suggest that school-based physical activity interventions led to an improvement in the proportion of children who engaged in MVPA during school hours **(+)**

Review details and objective	Inclusion criteria and methods	Studies included, main effect and findings [1]
Objective: To summarize the evidence of the effectiveness of school-based interventions in promoting physical activity and fitness in children and adolescents.	- **Participants:** Children and adolescents (aged 6 to 18 years). - **Outcomes**: Rates of MVPA during the school day, time engaged in MVPA during the school day, body mass index (BMI), maximal oxygen uptake (VO2max), and pulse rate. **Methods:** Systematic review and narrative analysis.	- Children and adolescents exposed to the intervention also spent more time engaged in MVPA (with results across studies ranging from five to 45 min more) and had improved VO2max (results across studies ranged from 1.6 to 3.7 mL/kg per min).
Brown et al. (2016). *Obesity Reviews.* [117] Family-based interventions to increase physical activity in children: A systematic review, meta-analysis and realist synthesis. **Objective:** To review existing intervention studies which explicitly engage the family to increase physical activity in children.	**Inclusion criteria:** - **Participants:** Healthy participants aged 5–12 years. - **Intervention:** Having a substantive aim of increasing physical activity by actively engaging the family. - **Outcome:** Reporting a physical activity outcome (subjective or objective). **Methods:** Systematic review, realist synthesis and meta-analysis.	**Studies included:** 47 (Quality assessment: 3 received a strong rating, 21 moderate and 23 weak). 18 studies were included in the meta-analysis **Main effect:** Meta-analysis revealed a significant small effect in favour of the experimental group (standardized mean difference: 0.41; 95% CI: 0.15 to 0.67). Sensitivity analysis, removing one outlier, reduced this to 0.29 (95% CI: 0.14 to 0.45). **(+)** Realist synthesis (28 studies) provided insight into intervention context (particularly, family constraints, ethnicity and parental motivation), and strategies to change physical activity (notably, goal-setting and reinforcement combined).
Borde et al. (2016). *Obesity Reviews.*[118] Methodological considerations and impact of school-based interventions on objectively meaured physical activity in adolescents: a systematic review and meta-analysis.	**Inclusion criteria:** - **Design:** Randomised controlled trials with a control group who did not receive an intervention aimed at increasing physical activity. - **Participants:** Studies that included adolescents with a study mean age of 10 years or older.	**Studies included:** 13 met the inclusion criteria and 12 were included in the meta-analysis. **Main effect:** The pooled effects were small and non-significant for both total physical activity (Standardized mean difference: 0.02 [95% CI: -0.13 to 0.18]) and

Review details and objective	Inclusion criteria and methods	Studies included, main effect and findings [1]
Objective: To determine the impact of school-based interventions on objectively measured physical activity among adolescents.	- **Intervention:** School-based interventions aimed at increasing physical activity. - **Outcome:** Total physical activity and or MVPA measured using accelerometery. **Methods:** Systematic review, meta-analyses and moderator analyses.	MVPA (Standardized mean difference: 0.24 [95% CI: -0.08 to 0.56]). **(-)** - Sample age and accelerometer compliance were significant moderators for total physical activity, with a younger sample and higher compliance associated with larger effects.

[1] Legend: (++) = significant positive effect, (+) = small to moderate positive effect, (-) = negligible or no effect

1.3 Health Inequality

1.3.1 Concepts of health inequalities

The WHO defines health inequalities as *'differences in health status or in the distribution of health determinants between different population groups'*.[105] Some differences in health, such as those attributable to biological variation, can be deemed unavoidable. However, those attributable to the external environment and conditions outside of an individual's control are often avoidable. Such differences in health that can be seen as unnecessary, unfair and unjust, are considered health inequities.[119,120]

The key distinction that can be made between the terms inequality and inequity is that the former is a dimensional description to refer to the unequal distribution of health or health resources, while the latter is accompanied by a moral judgment that the inequality is wrong.[30,121] While this distinction between the two definitions is commonly used across the North American academic literature, in the UK, the general term health inequalities is more frequently used to encompass both. Public Health England describes health inequalities to be *'avoidable and unfair differences in health status between groups of people or communities'*.[122] This definition of health inequalities as encompassing a moral judgement with regards to the unfairness of differences is used throughout this dissertation.

1.3.2 Determinants of health inequalities

Health inequalities are ultimately underpinned and driven by differences in the broad social and economic conditions in which people are born, grow up in, live in, work and age. The social and economic circumstances that together determine the health of individuals and populations are called the '*social determinants of health'.* The mechanisms through which social determinants drive differences in health and well-being across the lifespan operate in complex and interrelated ways.[123]

The Dahlgren and Whitehead model of health determinants outlined in Figure 1.5,[120] is a widely used framework that describes the main determinants of health separated into layers of influence. Individual health at the core of the model (which is influenced by core non-modifiable factors including age, sex and genetics) is driven by a range of determinants including: individual lifestyle factors (such as physical activity, smoking and diet), social and community networks (including families and social circles), an individual's living and working conditions (including access and opportunities in relation to jobs, housing, education and welfare services), and ultimately the socioeconomic, cultural and environmental conditions driven by the overall macro-level policies prevailing in a country or region (such as disposable income, taxation and the availability of work).[122,120]

Given that all health inequalities are directly or indirectly generated by social, economic and environmental factors, and structurally influenced lifestyles, the resulting differences in the incidence of disease, health outcomes or access to health care are accordingly amenable to change.

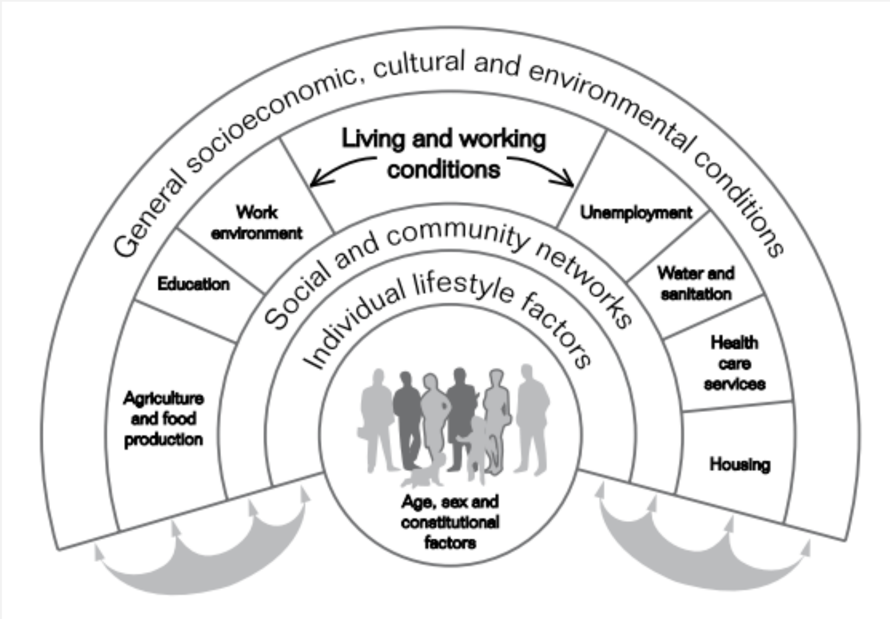


Figure 1.5 Model of Health Determinants, Dahlgren and Whitehead [120]

1.3.3 Drivers of health inequalities

There are many explanations and suggested mechanisms driving the association between socioeconomic disadvantage and health. The Black Report, published in 1980,[124] was the landmark study revealing established and widening social class inequalities in health in the UK. The report set out four mechanisms (artefact, social selection, behaviour and material circumstances) to explain widening inequalities. Following decades of subsequent research, Bartlett and Blane in 2008, proposed that up to date understanding of mechanisms fit across four major models: materialist, psycho-social, life-course and behavioural.[125,126]

The materialist model encompasses access (and lack thereof) to resources that drive differences in health. This covers a wide range of resources including environmental exposures (e.g. higher levels of air pollution in inner city neighbourhoods) and neighbourhood characteristics (e.g. access to parks and bicycle lanes). The psycho-social model proposes that social inequality effects how individuals feel, which affects body chemistry and eventually health (e.g. stressful circumstances produce emotional responses which increase cardiometabolic risk factors). The life-course model, which is the most recently developed, emphasizes patterns of accumulation of social, psycho-social and biological advantages and disadvantages over time. This model was developed in consideration of multiple studies demonstrating that health disadvantages accumulate over the lifespan.

The final model focuses on the role of health behaviours. Considering differences in health damaging and promoting behaviours between social class groups, a central component of research on the emergence of inequalities in obesity and NCDs focuses on health behaviours. Four leading behavioural risk factors (harmful use of alcohol, tobacco use, dietary behaviour and physical inactivity) are considered central drivers of increasing levels of NCDs.[10] These health behaviours can lead to overweight and obesity, raised blood pressure, raised cholesterol, and eventually disease.[127] Evidence reveals that these health behaviours are often socioeconomically patterned across populations, contributing to differences in health.[128,129]

There is general agreement that a combination of explanations and mechanisms drawn from these models is needed to explain social gradients in morbidity and mortality. Each mechanism and model on its own is insufficient in explaining the observed gradients.[130,131] The remainder of this thesis focuses on the contribution of behavioural pathways and mechanisms, however recognises the importance of the diverse set of models and influences discussed above.

1.3.4 Equity characteristics

Inequalities in health behaviour and outcomes can be considered across a multitude of sociodemographic factors which each act as potential markers of different aspects of disadvantage. The characteristics that are proposed to be worthy of research attention within public health and medical research are outlined in a framework constructed by the Cochrane Equity Group.[132] This framework, called '*PROGRESS Plus*', includes the place of residence, race or ethnicity, occupation, gender, religion, education, social capital and socioeconomic status (assumed to be equivalent in SEP in this thesis), plus age, sexual orientation and disability for each individual. The definitions of each factor included in the PROGRESS Plus framework are summarised in Table 1.4.

Originally developed by Evans and Brown,[133] the framework has evolved to support an equity perspective in the conduct, reporting and use of research, and acts as a reminder of the personal and population characteristics across which equity may be important. Given that the impact disadvantage has on behaviour and health varies, the equity characteristics that should be considered will differ between populations and contexts. For example, certain factors (e.g. occupational, social capital, sexuality) are not relevant within child and adolescent populations. Accordingly, the PROGRESS Plus framework is better used as a tool for applying an 'equity lens' to research, instead of as a definitive checklist.[132]

Table 1.4 Progress Plus characteristics [134]

PROGESS Plus Factor	Description
Place of residence	Locations in which individuals reside or perceptions of their location.
Race	Self-identified racial or ethnic group or other classifications of culture or language. This includes nationality status (e.g. refugee or migrant).
Occupation	Occupational situation, patterns of work or features of the working environment.
Gender	Sex refers to the biological and physiological characteristics that differentiate men and women. Self-identified gender incorporates ideas around socially constructed roles or differences in behaviour attributed to men and women.
Religion	An individuals' religious affiliation or system of religious or spiritual beliefs or values.
Education	Self-reported extent and type of schooling, education or other formal training or learning undertaken.
Social capital	A multifaceted concept capturing the obligations and benefits conferred upon an individual by society and social relationships. This can be seen as a measure of interconnectedness between an individual and their social surroundings or group.
SES	An individual's position within a hierarchical social structure. Measures of SES aim to capture access to resources, privilege, power or control based on socioeconomic considerations.
Age	Self-reported age in years.
Disability	A term incorporating ideas surrounding impairment, activity limitation and restrictions on the ability to participate in certain life situations. Disability can be both mental and physical.
Sexual orientation	Self-reported sex towards which an individual feels attraction or self-defined sexual identity.

1.3.4.1 Socioeconomic position

One of these equity factors, socioeconomic position (SEP), is recognised by the WHO as a central and influential determinant of differences in health, across all societies globally.[135] SEP is a complex, multidimensional concept that comprises a range of economic factors including resources and power that influence what positions individuals or groups hold within the structure of a society.[136,137] Accordingly, SEP affects health across the life course, at different levels (e.g. individual, household, neighbourhood), and through different causal pathways.[138] Given its universal impact and the opportunity to alter it, SEP is a commonly named target and focus for policy makers and governments tackling health inequalities.[139]

SEP additionally intersects and influences health inequalities apparent by multiple other equity factors. For instance, socioeconomic resources are suggested to be a central driver of risk factor and health differences between ethnic groups.[140] It also intersects with behaviour and health differences seen by place of residence, occupation, education and social capital. While investigating multiple equity characteristics (including gender, ethnicity, place of residence and religion), this dissertation focuses on SEP and its influential role in the development and propagation of health inequalities.

1.3.5 Measurement of SEP in children

The measurement of an individual's SEP is complex as definitions and indicators vary, and are both culturally and contextually influenced.[141–143] Furthermore, indicators and their applicability differ at varying points across the life course. Evidence suggests that parental education and occupation, household income and conditions are the most important socioeconomic indicators during childhood.[142,144] Each of these indicators are described in Table 1.5, including their individual advantages and limitations.

Unlike physical activity, there is no gold-standard indicator for SEP.[145] For any given analysis the most appropriate indicator depends on the study population, context and research question posed. Accordingly, throughout this dissertation the SEP indicator selected is dependent on the research question and how SEP is conceptualised within the specific context. Wherever possible, multiple indicators of SEP are used to investigate differences in findings.

Within analyses pooling SEP data from multiple countries, I prioritised parental education as the selected indicator of SEP. Parental education is a strong predictor of children's health,[146,147] and particularly valuable in multi-country studies as it places individuals within a comparative ranking (e.g. completion of compulsory versus post-compulsory education) which can then be harmonised across country boundaries to create comparable outcomes. Other indicators of occupation and household assets are comparatively more restricted and specific to national contexts.

Table 1.5 Measures of socioeconomic position (SEP) in children including advantages and limitations [142,144]

Indicator and definition	Advantages	Limitations
Parental education: Years of formal education completed or qualifications attained	- Relevant to people regardless of age or working circumstances - Is suggested to be less contentious then other indications of wealth (e.g. income) - Is possible to harmonise across national contexts	- Accuracy of measurement is limited to participants who went to school within the host country - Number of years of education contains no information about the quality of the education - Meaning varies for different birth cohorts - Ease, cost and social expectations of educational attendance vary across time and places - When years of completed education is used no account is taken of repeating school years
Parental occupation: Current or longest held occupation by parents, which are subsequently placed into occupational groupings	- Comparatively high availability in many routine data sources included census data and death certificates - Occupation is strongly linked to income and therefor has a decently direct relationship with material resources - Wide variety of occupational groupings (E.g. The Registrar General's Social Classes, Erikson and Goldthorpe Class Schema, UK National Statistics Socio-Economic Classification, Wright's Social Class Scheme, Occupational-based census classification)	- Greater complexity of occupational life in low-resource country settings creates challenges – parents are more likely to have multiple jobs, employment may be seasonal, families may rely on subsistence farming or small home enterprises - Cannot be readily assigned to people who are not currently employed and accordingly when used can underestimate socioeconomic differentials due the exclusion of some people (commonly excluded groups include the unemployed, retired groups, those working inside the home, students and people working in unpaid, informal or illegal jobs) - Some groups are less willing to disclose their occupation - Different meanings for different birth cohorts and geographical settings challenge international comparisons
Annual household income: Absolute individual parental or household income per number of people dependable on that income	- Most direct measure of the material resources of SEP - Is the most responsive indicator changing on a short term basis - Has a dose-response relationship with health	- Is difficult to measure and unreliable in low resource country settings due to greater reliance on the informal economy, self-employment and seasonal activity - Is a sensitive question and subject to greater non-response than other measures of SEP

Indicator and definition	Advantages	Limitations
		- Meaning of income varies by age groups. As it follows a curvilinear trajectory is most accurate for young and older adults - Accurate methods of collection take space and time
Household assets: aggregate measures of a grouping of household amenities that act as markers of material circumstances	- Are easily adaptable to varying cohorts or contexts under study - Are comparatively easy to collect - Specific to the area in which they were developed - Often able to collect with a degree of accuracy in children without having to go to the parent - Specificity means that they are able to provide some indication of specific mechanisms linking SEP to particular health outcomes	- Are specific to the temporal and geographical context where they were developed and thus can be difficult to compare across studies - If not adapted can be quite inaccurate as meaning of amenities substantially varies between contexts - Can be less able to differentiate between individuals within high resource country contexts where there are less differentials in access to amenities (e.g. toilets, running water, cell phones, cars)
Area level measures (indices of deprivation): usually used to characterise areas on a continuum from deprived to affluent	- Are commonly easily accessible through census or other administrative databases - Low participant burden as can often be linked to data following data collection	- Are less strongly associated to individual health outcomes so often underestimate impact on health - Remains unclear if associations between area level measures of socioeconomic circumstances and health outcomes are related to the socioeconomic characteristics of where people live, independently of the lifetime characteristics of people living in these area

1.4 Inequalities in NCDs, obesity, physical activity and interventions

1.4.1 Inequalities in NCDs

Health inequalities driven by social and economic factors are among the most consistently observed and persistent epidemiologic findings across the entirety of the life course. At every life stage gradients are evident, with disadvantaged populations faring worse with regards to disease risk prevalence, and accordingly life expectancy.[148] Decreases in health associated with lower SEP follow a linear, stepwise trend and accordingly are often referred to as the '*social gradient in health*'.[149] Socioeconomic inequalities in the unequal distribution of the burden of NCDs are widespread and present at the global, national and regional levels.

Globally, 78% of the 57 million deaths from NCDs in 2016, occurred in LMICs, where the majority of global population is located.[150] Driven by poverty, globalization, urbanization and population growth, the burden of chronic disease in low-resource national contexts is continuing to rise.[127] However, irrespective of the income level of a country, NCDs consistently and disproportionally effect the poorest. Within the UK, cardiovascular mortality rates are significantly higher in regions with overall lower levels of socioeconomic resources including Scotland and the North of England, comparative to the South of England.[151] Inequalities in morbidity and mortality are evident and widespread even between individuals with different socioeconomic resources living within the same city. For instance, a baby born in the least affluent neighbourhood of Glasgow in comparison to the most affluent, can expect to live on average 10 years less.[152]

1.4.2 Inequalities in obesity

These inequalities in morbidity and mortality from NCDs are expected to continue to widen in consideration of growing differences in obesity between socioeconomic groups.[2] Across most countries, rates of obesity are increasing at the fastest rate within socioeconomically disadvantaged populations.[105] While once considered diseases of affluence in LMICs, recent evidence demonstrates the clustering of obesity within low income populations alongside national economic development.[153,154] Predictions forecasting that by 2030, 60% of the global adult population will be overweight or obese, are expected to encompass significant widened inequalities between advantaged and disadvantaged populations.[155]

Parallel to these findings for adult populations, a disproportion burden of rising childhood obesity rates are concentrated within socioeconomically disadvantaged populations. In England, children living in the most deprived 10% of areas are more than twice as likely to be obese then a child living in the least deprived 10%.[156] Recent data from the NCMP measurement programme illustrate that prevalence rates are stabilizing or decreasing in affluent communities and increasing in deprived communities, leading to further widened population inequalities (See Figure 1.6).[157] Elevated rates of childhood adiposity are also prevalent across many societies within certain ethnic minority subgroups,[158] which are suggested to be at least partially linked to differences in socioeconomic resources.[159]

Widening inequalities in childhood obesity are concerning given that differences progressively worsen with age, thus amplifying inequality across the life-course.[160,161] Reducing inequalities in childhood obesity and the burden on disadvantaged groups is a priority in the UK,[39] Europe,[86] and globally.[162] However, despite these clear trends and the prioritization of in national agendas, we have limited understanding of the factors driving widening obesity inequalities between socioeconomic groups of children.[163–165]

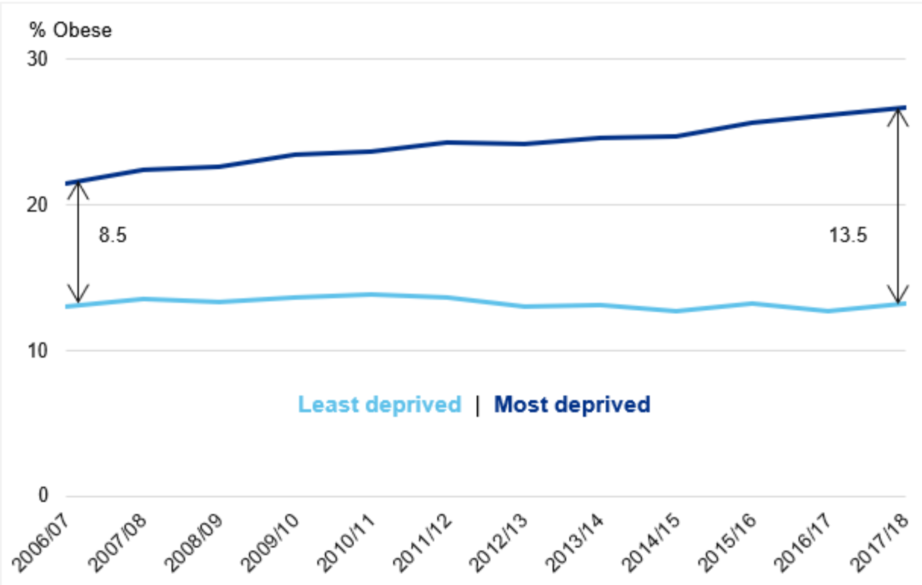


Figure 1.6 UK National Child Measurement Programme: Childhood obesity prevalence (%) by level of deprivation from 2006/07 to 2017/18 in Year 6 (10-11 year-olds) [157]

1.4.3 Inequalities in children's physical activity

Consistent evidence suggests a significant association between SEP and overall physical activity in adults.[166] Comparatively, findings for children and adolescents younger than 18 are inconclusive, with no established associations between physical activity and SEP.[166] In pre-school children, SEP is consistently found to be unrelated to overall physical activity levels or MVPA in systematic literature reviews.[167–169] In reviews of the physical activity behaviour of both children and adolescents, SEP is similarly found to not be significantly related to physical activity levels.[91,92] When separating children and adolescents, the findings are varied and inconsistent.[92,170,171]

The children's physical activity evidence base is limited by the cross-sectional design of most studies. Another reason suggested for the inconsistent associations is the diversity of activity domains and components analysed across the literature (E.g. physical activity in break-time, across the school day, in the after school period, across the full day).[166] The vast majority of this evidence is from high-income countries. Due to a shortage of evidence we do not know if the association (or lack thereof) between SEP and physical activity is consistent within LMCs.[87]

Based on current evidence, clear socioeconomic inequalities in obesity in childhood are not explained by socioeconomic differences in physical activity. In line with international guidelines to engage in 'MVPA for at least 60 minutes per day', most research investigating socioeconomic differences has assessed physical activity as the aggregate of MVPA. However, moderate physical activity (MPA) and vigorous physical activity (VPA) are generally accumulated through different types of activities (e.g. walking to school vs. sport participation), which may be differently distributed across the population. Differences in physical activity intensities between socioeconomic groups and the potential contribution to obesity inequalities, are underexplored. It furthermore, is unclear if associations between socioeconomic inequalities and physical activity intensities differ across national contexts.

1.4.4 Drivers of inequalities in children

Evidence suggests that some population strategies to prevention may inadvertently increase socioeconomic inequalities in health by disproportionately benefiting those at lower risk and ultimately widening the gap between the most and the least disadvantaged.[6] This evidence raises the validity of the underlying assumption of Rose's population strategy of prevention: *the impact will be the same for everyone regardless of where one falls on the population distribution.*[103] The likelihood of disadvantaged populations to not benefit equally has been suggested to depend on the nature of the preventative strategy and if it is structural (targets conditions) versus agentic (targets behaviours).[172]

Differential effectiveness, commonly termed 'intervention generated inequalities', ensues when interventions provide greater benefit to one population group over another.[6] As illustrated in Figure 1.7, inequalities can be generated at multiple stages throughout the intervention process. These effects are concerning when an intervention provides greater benefit to advantaged than to disadvantaged groups. There is both theoretical and empirical evidence that some public health interventions exacerbate existing inequalities through differential effects between subgroups of the population. [173]

It is unclear if children's physical activity interventions generate differential effects. Evidence from individual evaluations of children's physical activity interventions have revealed inequalities being generated at multiple points across the intervention process including by differential provision of, and access to, interventions and resources,[174] variation in intervention uptake,[175] differential intervention efficacy,[176,177] differential long-term compliance[178] and differential response in evaluations.[179] While these studies offer individual examples, there is not a coherent overall understanding of the direction and size of equity effects across the wider literature.

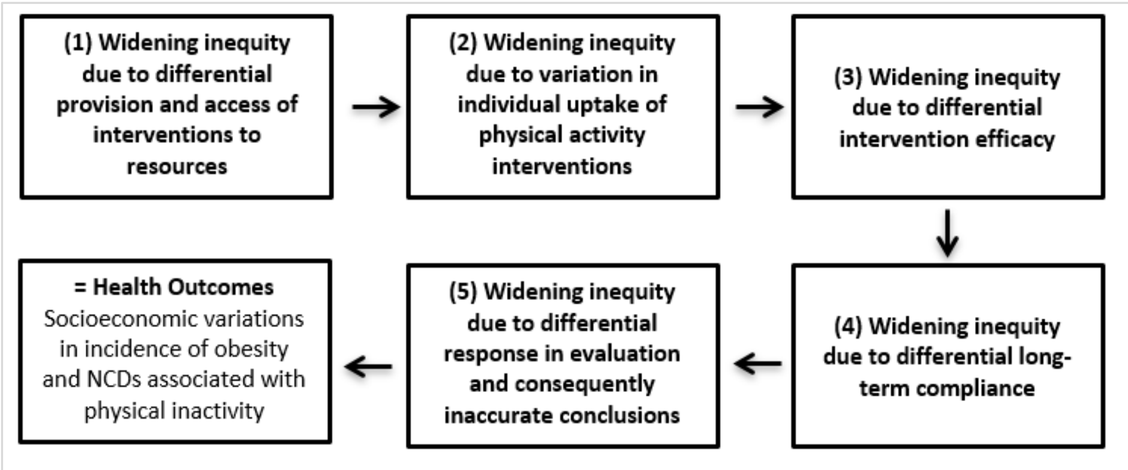


Figure 1.7 Points in the intervention process where inequalities may be generated [6]

1.5 Objectives and aims

To effectively reduce health inequalities, a better understanding of the variations in patterns of physical activity in children from different levels of SEP is needed. Furthermore, greater knowledge of differential effects of existing interventions is critical to developing programs that can effectively and equitably change behaviour. Given these identified gaps in the evidence, my PhD investigates existing inequalities in children's physical activity behaviour and interventions and is separated into two sections.

The first part, across three individual analyses, investigates variations in intensities and patterns of children's physical activity behaviour by SEP with an aim of understanding potential contributions to inequalities in obesity rates. This research examines differences within UK children using the Millennium Cohort Study (MCS) and South African adolescents using the Birth to Twenty Cohort Study (BT20+). This is followed by a cross-country study in the DEDIPAC children's accelerometer database investigating socioeconomic differences in physical activity intensities and obesity across 16 European countries, and if these relationships differ by national level economic inequality.

The second part, across two chapters, explores the equity effects of children's physical activity interventions. Initially, a scoping review assesses and summarizes the availability of evidence on differential effects of children's physical activity interventions. This is followed by an in-depth analysis determining the effectiveness and equity of a subset of school-based physical activity interventions.

The specific research questions across the two sections and accompanying chapters are outlined below and in Figure 1.8.

Part 1 (Chapter 2, 3 and 4): Assessing socioeconomic variations in the patterning and intensity of children's physical activity behaviour:

- Do the patterns and intensities of children's physical activity differ by SEP?
- Does this relationship of SEP to physical activity intensities differ across national contexts?

Part 2 (Chapter 5 and 6): Exploring the equity effects of children's physical activity interventions and determining the effectiveness and equity of school-based interventions:

- What is the availability of evidence on the differential effects of children's physical activity interventions?
- Do intervention or study characteristics influence the likelihood of reporting of differential effects?
- Are school-based physical activity interventions effective in changing children's minutes of MVPA across the full day? Is this equitable by subgroups of SEP and gender?

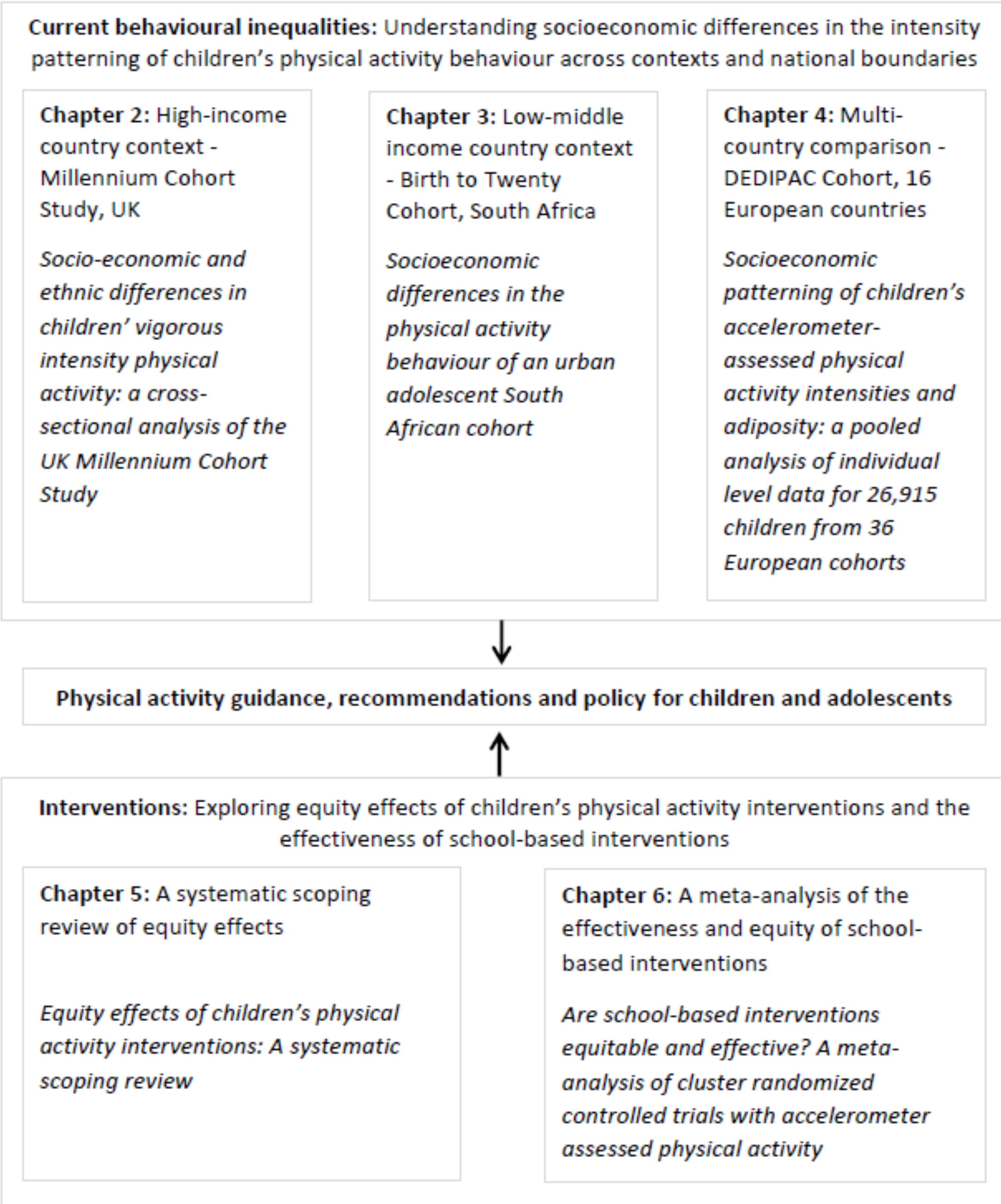


Figure 1.8 Figure of PhD Analyses

2 Socioeconomic and ethnic differences in children’s vigorous intensity physical activity: A Cross sectional analysis of the UK Millennium Cohort study

This work is published as: Love R, Adams J, van Sluijs EMF. Socioeconomic and ethnic differences in children’s vigorous intensity physical activity: a cross-sectional analysis of the UK Millennium Cohort Study. 2019. BMJ Open. (In press). It was presented at the International Society for Behavioural Nutrition and Physical Activity Annual Meeting, Hong Kong, June 2018 (Both as a poster and as part of an invited PhD Keynote Talk).

2.1 Introduction

This chapter is the first of three epidemiological analyses exploring equity differences in the intensity patterning of children's physical activity behaviour. This analysis investigates differences in the proportions of MPA and VPA accumulated by UK children from differing levels of SEP and ethnicity using the Millennium Cohort Accelerometer Study.

2.2 Background

Recent and rising prevalence rates of childhood obesity have been accompanied by widening inequalities between socioeconomic groups. By age 11, UK children from lower income families are three times more likely to be obese than their more advantaged counterparts.[156] These differences progressively worsen with age.[160,161] There are also stark ethnic and racial differences in childhood adiposity, with higher rates of obesity within certain ethnic minorities including Black British and Bangladeshi children.[158,159] It is suggested that these differences are partially related to existing differences in socioeconomic resources between ethnic groups.[159] At present, there is limited understanding of the modifiable factors driving socioeconomic and ethnicity-related inequalities in childhood obesity in the UK.

Previous research using objectively measured physical activity has demonstrated no socioeconomic patterning in children's adherence to the international guidelines to engage in 'MVPA for at least 60 minutes per day'.[49,180,181] While there is some evidence of ethnic differences in activity levels,[94] these analyses are confined to the use of aggregated MVPA to quantify activity levels. Consistent evidence suggests that VPA is more strongly associated with reduced waist circumference and adiposity relative to lower intensity activity, including MPA.[74–78] It is possible the predominate focus on MVPA may be why physical activity only explains a small portion of the socioeconomic gradient in overweight risk for UK children.[182]

The importance of intensity specific differences of MVPA in explaining socioeconomic and ethnic inequalities in health remains underexplored. Considering that MPA and VPA are accumulated through different types of activities (e.g. walking to school vs. sport participation),[37] they may be differently distributed in population subgroups. In high-income countries including the UK, children's participation in the organized sports activities that drive VPA have been shown to be socioeconomically patterned due to unequal access, support and costs.[48,183,184] Furthermore, children from certain ethnic minorities have been shown to face additional barriers to sport participation due to cultural and religious factors, lack of access and parental safety concerns.[96]

The need for understanding these intensity differences is strengthened by evidence suggesting that the age-related decreases in VPA observed annually into adulthood are more pronounced in non-white and socioeconomically deprived children.[100] This analysis proposes that socioeconomic and ethnic differences in children's higher activity intensity could help to explain well established socioeconomic and ethnic gradients in obesity. Thus, the objective of this study was to investigate if daily VPA, adjusted for minutes of MPA performed, differs by SEP or ethnicity in a large sample of UK children, 7 years of age.

2.3 Methods

2.3.1 Sample

This analysis used data from the Millennium Cohort Study (MCS), a nationally representative, longitudinal study of children born in the UK between September 2000 and January 2002.[185] MCS was developed to track the social, economic and health experiences facing children born at the start of the 21st century. The original cohort included 18,818 children. Data was first collected when cohort participants were 9 months old through a home-based interview (72% of those initially contacted provided information). Subsequent follow-up interviews at ages 3, 5, 7 and 11 years were conducted in the home environment with the main respondent (primarily the natural mother, and where applicable the partner).[186] At the fourth follow-up at age 7 an accelerometer study was conducted with participants. Parental consent and child assent was obtained for participation in the accelerometer study.

To ensure adequate representation of all four UK countries, including disadvantaged and minority populations, a stratified clustered sampling design was used to oversample children living in Wales, Scotland and Northern Ireland, disadvantaged areas, and communities with high proportions of minority ethnic groups.

The MCS received ethics approval from the South West and London Multi Centre Research Ethics Committees, UK and the Yorkshire Research Ethics Committee.

2.3.2 Physical Activity

At the MCS fourth follow-up, participating children (n=13,681) were invited to take part in an accelerometer study. Assenting children were sent a pre-programmed Actigraph GT1M accelerometer (Actigraph, Pensacola, Florida), set to record data at 15-second epochs lengths.

Actigraph accelerometers have been shown to be reliable and valid in comparison to measures of physical activity derived from heart rate monitoring, indirect and room calorimetry, and doubly labelled water.[50–52] Children were instructed to wear the accelerometer on an elastic belt around their waist for 7 days throughout all waking hours (except during aquatic activities or contact sports), and to return it by post. Children were additionally asked to complete a monitor wear log to help identify times when the accelerometer was not worn (non-wear time). Data was collected over a 15-month period between May 2008 – August 2009.

All data collection and processing was performed in-house, according to predetermined criteria.[187] Data was downloaded using Actigraph software V.3.8.3 (Actigraph, Pensacola, Florida, USA) and processed according to predetermined criteria, using the R statistical package pawacc.[187] Non-wear time, defined as 20 minutes or more of consecutive zero activity counts, were excluded from the analysis. Counts were separated into sedentary (<100 counts per min (cpm)), moderate (2,240-3,840 cpm) and vigorous (>3,841 cpm) categories.[187] Extreme values above a threshold of ≥11,715 cpm were excluded, as this may indicate a faulty monitor. To ensure reliable estimates of activity, the sample was restricted to participants with 3 valid days of data (≥ 10 hours per day, including at least 1 weekend day).[188] The sample was restricted to one child per participating family.

2.3.3 Sociodemographic variables

Considering strong evidence that health and obesity is patterned strongly and independently along both socioeconomic [165,189,190] and ethnic [191,192] lines, my analysis examines the association with both indicators. Information pertaining to SEP and ethnicity were collected from participants at this fourth follow-up point. SEP was measured using maternal education and equivalised household income. Maternal education captures the socioeconomic circumstances that affect a child; this measure is advantageous as it can be applied to mothers irrespective of whether or not they are in paid employment at the time of interview.[193] Maternal education was categorized into five groups: none (qualifications less than those currently expected when leaving school at 16 years); low (qualifications comparable to those currently expected when leaving school at 16 years); medium (qualifications comparable to those currently expected when leaving school at 18 years); high (qualifications greater than medium, but not higher); and higher (any higher educational qualifications).[194] Annual household income was equivalized for household composition based on guidance from the Organisation for Economic Co-Operation and Development (OECD).[185] Ethnicity was parent-reported and categorised in my analyses as: white, any mixed, Indian, Pakistani or Bangladeshi, Black or Black British, or other. Parents were asked to select from a longer list which ethnic group they identify most with (e.g. Black includes those who identified as Black Caribbean, Black African and Black British). The ethnic classifications utilized were based on census categories in accordance with guidelines from the Office for National Statistics.[195]

2.3.4 Statistical analysis

Multivariable linear regression models were fitted to analyse differences in absolute mean daily minutes of VPA achieved across socioeconomic and ethnic groups, adjusting for mean daily minutes of MPA, mean accelerometer wear time, season of measurement, age and sex. Separate models were run for each exposure variable (maternal education, equivalised household income, ethnicity) to assess the effects of each variable seperately.[196] Models were also run separately for week and weekend days as there is evidence that children accumulate physical activity differently on weekdays and weekend days.[197] It is possible that socioeconomic and ethnic subgroups of children engage in different types of activities with distinct weekly patterning (e.g. weekend sports).

All model residuals were assessed for normality. To investigate effect modification by gender, interactions were run across all models. In sensitivity analyses, additional adjustments for BMI were explored. All analyses were conducted using STATA 15.1 software, with survey commands used to account for the stratified clustered design of MCS and to obtain robust standard errors.[198,199] Sampling weights adjusting for unit nonresponse between waves were utilized.

To support the premise of the current analyses that VPA is most strongly associated with adiposity, additional linear regression models were fitted to study differences in BMI z-score by mean daily minutes of VPA and MPA separately, adjusting for accelerometer wear time, age and sex.

2.4 Results

Of the 12,872 children that consented to the accelerometer study, 9,772 returned the accelerometers, with a final sample of 6,497 children following in-house processing by MCS.[200] Application of my study inclusion criteria resulted in an analytic sample of 5,172 children. This drop was predominately driven by the requirement that participants have '3 or more valid days', and the inclusion of one weekend day to enable comparisons across weekend and weekdays. On average, children in the analytic sample were 6.8 years of age (SD: 0.4) and 50% female (see Table 2.1). Overall, 14.4% of girls and 11.7% of boys were overweight, whilst 4.1% and 3.5% were obese. These classifications were made through application of the WHO Growth Standards to produce age and gender specific z-scores utilizing Stata functions zanthro and zbmicat.[201] The sample included children from each country across the UK (England, Wales, Scotland and Northern Ireland). Sociodemographic and physical activity summary characteristics of the analytic sample are outlined in Table 2.1 and Table 2.2, respectively. These two tables of sample characteristics are based on the weighted sample. Drop out analyses showed that those participants included in the analytic sample (n=5,172) were more likely to come from a higher income household, have mothers with higher levels of education, and be male when compared to participants who provided accelerometer data but did not meet the criteria for the analytic sample (n=1,325).

Multivariable linear regression models revealed significant differences in the minutes of daily VPA accumulated across socioeconomic subgroups (Table 2.3). The full model details are included in A2.1-A2.3. Significantly more minutes of daily VPA was accumulated in each level of maternal education compared to those whose mother indicated 'no qualifications'. This relationship was more pronounced on weekdays than on weekend days. Analyses by equivalized household income supported this, indicating significantly more time spent in VPA with increasing household income. Figure 2.1 illustrates this effect and shows the proportion of VPA within daily MVPA by categories of activity with participants stratified into tertiles of equivalised household income. This figure demonstrates that irrespective of activity level, children from higher affluence families accumulate a greater proportion of their daily MVPA from higher intensity activities.

Pakistani & Bangladeshi children performed on average over 3 minutes less daily VPA in comparison to white British children overall, on weekdays as well as on weekend days. This difference was slightly more pronounced on weekdays, versus weekend days. Children from 'other ethnic groups' also accumulated less daily VPA overall and on weekdays (2.2 and 3 minutes less, respectively). In contrast, children of mixed ethnic descent accumulated comparatively more minutes of VPA daily across the week and on weekdays, but not weekend days.

There were no significant interactions with gender in any model. Additional adjustments for BMI z-score did not change the pattern of results (See A2.4). Supporting multivariable linear regression models for BMI z-score revealed a significant association between daily minutes of VPA and BMI z-score, with a 1-minute difference in VPA associated with 0.012 (95% confidence interval (CI): -0.017 to -0.007) lower BMI z-score (See A2.5). The association of daily MPA with BMI z-score was statistically significant, but substantially smaller (-0.002 [95% CI: -0.006 to -0.001]).

Table 2.1 Sociodemographic characteristics of the weighted sample: UK Millennium Cohort Accelerometer Study (N=5,172)

	Level	n (%)
Gender	Female	2,592 (50.1)
	Male	2,580 (49.8)
Country	England	3,390 (65.5)
	Wales	676 (13.1)
	Scotland	612 (11.8)
	Northern Ireland	494 (9.6)
Weight Status	Not overweight	4,296 (83.3)
	Overweight	663 (12.9)
	Obese	196 (3.8)
Ethnic group	White	4,543 (87.8)
	Mixed	130 (2.5)
	Indian	115 (2.2)
	Pakistani or Bangladeshi	194 (3.8)
	Black or Black British	127 (2.5)
	Other ethnic group	63 (1.2)
Maternal education	No qualifications	263 (5.1)
	Low	1,241 (24.0)
	Medium	787 (15.2)
	High	1,965 (38.0)
	Higher	447 (8.6)
	Overseas qual.	108 (2.1)
	None of these	361 (7.0)
Equivalised monthly household income (£), mean (SD)		1,700.9 (943.1)
Distribution of valid days		6.1 (1.2)
Age (years)		6.8 (0.39)

Table 2.2 Physical activity characteristics of the weighted sample: UK Millennium Cohort Accelerometer Study (N=5,172)

	All days [1]	Weekday [1]	Weekend [1]
Mean mins/day in sedentary behaviour	397.2 (68.3)	402.8 (70.8)	380.5 (91.9)
Mean mins/day in light activity	282.7 (40.5)	282.9 (42.9)	282.6 (54.5)
Mean mins/day in moderate activity	42.5 (13.2)	42.4 (13.6)	42.9 (19.1)
Mean mins/day in vigorous activity	19.9 (10.6)	20.1 (11.1)	19.4 (14.2)
Mean mins/day worn across all valid days	742.4 (63.1)	748.2 (66.1)	725.4 (88.3)

Note: all values are mean (SD)

Table 2.3 Multivariable linear regression models for mean minutes of VPA and MPA respectively, overall for all valid days, on weekdays and on weekend days, by socioeconomic and ethnic subgroups: UK Millennium Cohort Accelerometer Study (N=5,172)

		Overall			**Weekdays**			**Weekends**		
Exposure	Level	β-coef	[95% Conf	Interval]	β-coef	[95% Conf	Interval]	β-coef	[95% Conf	Interval]
					VPA minutes/week [1]					
Ethnic group (ref: white)	Mixed	1.47*	-0.06	3.00	1.57*	-0.14	3.28	0.43	-1.42	2.28
	Indian	0.74	-1.19	2.67	0.58	-1.23	2.39	0.76	-2.18	3.70
	Pakistani & Bangladeshi	-3.34***	-4.66	-2.03	-3.45***	-4.91	-1.99	-3.00***	-4.36	-1.64
	Black or Black British	-1.67	-3.96	0.61	-2.08	-4.47	0.32	-0.03	-3.44	3.37
	Other ethnic group	-2.27**	-4.16	-0.37	-3.07***	-5.31	-0.83	-0.14	-2.28	2.00
Maternal education (ref: none)	Low	1.31**	0.22	2.41	1.31**	0.11	2.52	1.34*	-0.06	2.73
	Medium	1.65***	0.53	2.77	1.72***	0.49	2.95	1.37*	-0.08	2.81
	High	1.81***	0.77	2.86	1.88***	0.73	3.03	1.63**	0.32	2.94
	Higher	2.96***	1.45	4.46	3.04***	1.39	4.70	2.80***	1.06	4.53
	Overseas qual.	2.28*	-0.30	4.85	2.12	-0.45	4.70	2.69	-0.67	6.05
	None of these	-0.45	-1.77	0.87	-0.60	-2.02	0.83	-0.07	-1.77	1.64
Equivalised income	Per £ 10,000/year	0.58***	0.32	0.84	0.61***	0.35	0.88	0.50***	0.18	0.82
					MPA minutes/week [2]					
Ethnic group (ref: white)	Mixed	-2.22**	-4.25	-0.19	-2.00*	-4.23	0.23	-2.13	-5.04	0.78
	Indian	-3.94***	-6.23	-1.65	-3.46***	-5.63	-1.30	-4.46**	-7.96	-0.96
	Pakistani & Bangladeshi	2.09**	0.33	3.85	2.00**	0.11	3.89	2.02*	-0.33	4.37
	Black or Black British	3.01***	1.07	4.95	3.10***	0.81	5.39	1.77	-0.96	4.49
	Other ethnic group	1.09	-2.30	4.47	1.89	-1.82	5.59	-1.34	-5.37	2.70
Maternal education (ref: none)	Low	-0.95	-2.59	0.69	-0.94	-2.69	0.81	-1.32	-3.38	0.75
	Medium	-1.48*	-3.15	0.19	-1.38	-3.16	0.39	-1.89*	-4.07	0.29
	High	-1.69**	-3.29	-0.09	-1.73**	-3.44	-0.03	-1.71*	-3.70	0.28
	Higher	-2.74***	-4.55	-0.92	-2.71***	-4.59	-0.82	-3.56***	-5.90	-1.22
	Overseas qual.	-1.96	-4.57	0.66	-2.29	-5.05	0.46	-1.74	-5.56	2.09
	None of these	1.98*	-0.05	4.01	1.88*	-0.31	4.06	2.35*	-0.31	5.00
Equivalised income	Per £ 10,000/year	-0.98***	-1.25	-0.70	-0.99***	-1.27	-0.71	-0.92***	-1.33	-0.50

[1] All models are adjusted for moderate physical activity, season of measurement, wear time, age and sex

[2] All models are adjusted for vigorous physical activity, season of measurement, wear time, age and sex

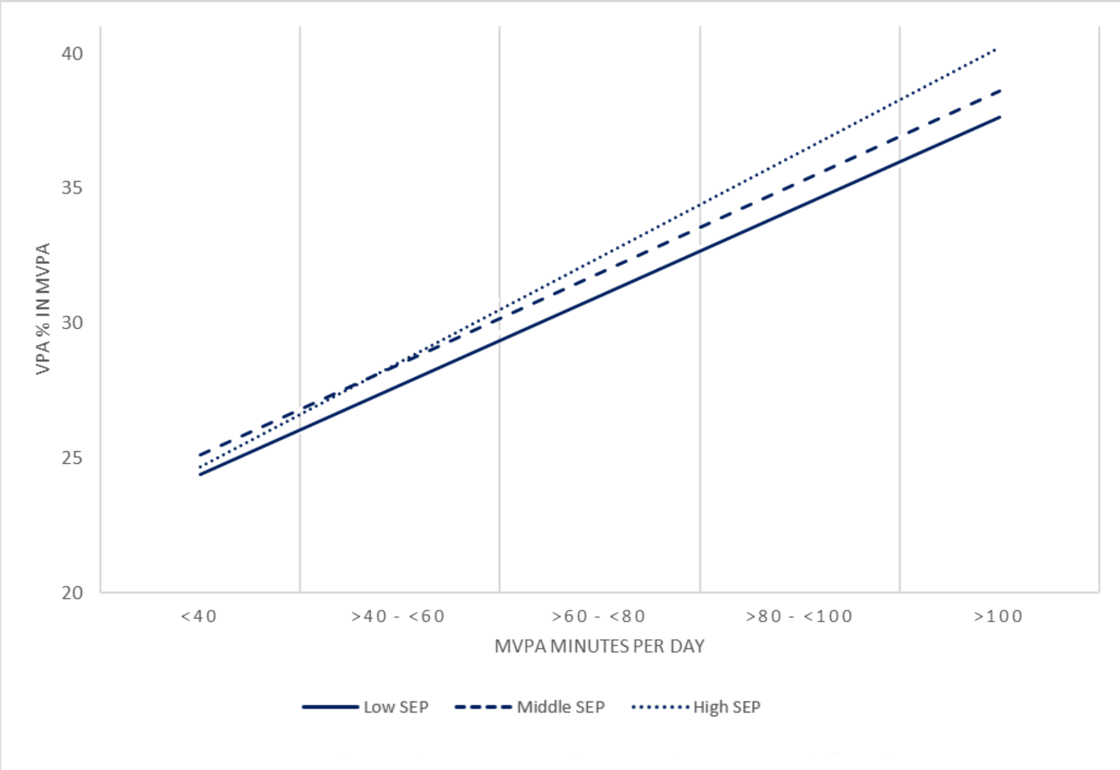


Figure 2.1 Proportion of VPA in daily MVPA, by level of activity (categories of MVPA, mins/day) with participants grouped by low, middle and high SEP: UK Millennium Cohort Accelerometer Study (N: 5,172)

Note: Tertiles of household equivalised income is used as indicator of SEP

2.5 Discussion

This chapter reveals clear socioeconomic and ethnic differences in children's time spent engaged in VPA. Children from less affluent backgrounds, alongside those from certain minority ethnic groups (Bangladeshi and Pakistani, other ethnic groups), accumulated less of their daily activity from VPA. These differences were consistent in both boys and girls, and mirror existing inequalities in childhood adiposity.[202] Although the effect sizes are relatively small, and possibly not clinically relevant at an individual level, I suggest that they are relevant at a population level and changes to reduce differences in VPA could have population-level implications for inequalities in adiposity in UK children.[203]

To my knowledge, this is the first study to investigate socioeconomic and ethnicity-related differences in the patterning of children's VPA, accounting for time spent in MPA. While prior studies have investigated activity intensity,[204] these did not account for MPA or have the capacity to investigate subgroups due to sample homogeneity. Accounting for MPA when analysing VPA is important given differences in the accumulation and distribution of overall activity across individuals. MCS offers the largest available representative accelerometer dataset of UK children. The cohort is strengthened by the stratified sampling design which enabled adequate representation of socioeconomically disadvantaged and ethnic minority children. The analysis is further enhanced by the comprehensive sociodemographic information provided by parent interviews. Much previous evidence relies on child-reported assessment of SEP, resulting in substantial missing or invalid data, with higher rates of non-response from socioeconomically deprived children.[205]

The findings of my models need to be interpreted in consideration of the limitations and my inclusion criteria, specifically the restriction to participants with at least 10 hours of wear time across 3 days. Like any birth cohort, representativeness of the MCS sample is affected by participant attrition between waves of assessment. Prior analyses of MCS have demonstrated that boys, certain ethnic minorities (Indian, Pakistan and Bangladeshi and Black Caribbean and African), and children living with only one parent were less likely to provide valid accelerometer data.[206] Drop-out analyses showed that the participants included in this analysis were more likely to be male and come from a higher socioeconomic background. Previous analyses have shown the presence of a missing-not-at-random mechanism in this cohort that results in the underestimation of the volume of physical activity during weekend days in this cohort.[207] This mechanism may have influenced my findings. Lastly, accelerometers underestimate activity involving vertical movement (e.g. cycling) and those for which the accelerometer was not to be worn (e.g. aquatic activities or contact sports). If these behaviours are also socioeconomically or ethnically patterned, this may have led to an under or overestimation of the true associations.

My supplementary analyses (A.2.5) support the well-established notion that VPA is more strongly associated with BMI z-score than MPA,[74,76–78] and point to a relevant effect size at a population level.[203] There are multiple reasons why the differences in VPA I observed may exist. Due to unequal access and costs, the organized contexts through which children accumulate VPA have been shown to result in differences in participation between more and less advantaged subgroups of children.[48,183,184] These findings are however based on questionnaire-based assessments which capture sports and organized activity more accurately than other types of activity.[208] Additional factors, including parental perceptions of time commitments, and the limited variety of activities accessible, are significant factors linked to low levels of VPA in low income families.[209] Furthermore, differences in home and family support for physical activity have been demonstrated between ethnic groups.[96] For instance, the presence of cultural and religious barriers have been found to impede participation in organized activity amongst Pakistani and Bangladeshi children, who in this analysis had the lowest levels of VPA. My findings also demonstrate that differences in VPA between children from families with high and low maternal education are more pronounced during the week. This may result from factors such as longer, inconsistent work hours within low-income jobs. These differences and differential barriers should be considered when developing interventions to increase VPA, and potentially impact obesity prevalence, in all groups. Furthermore, this finding highlights the potential of school-based and after-school sports clubs to contribute to a solution for reducing existing behavioural inequalities. Despite known differences in boys' and girls' MVPA,[210] also in this cohort,[94] the lack of gender interaction in this analysis reveal that both girls' and boys' participation in VPA are equally affected by socioeconomic and ethnic factors.

International physical activity guidelines for children focus on MVPA in part because increases in MVPA are hypothesised to be easier to achieve than VPA at a population level.[211] My findings indicate that by utilizing the aggregate measure of MVPA we may be overlooking significant differences in the relative participation in MPA and VPA between population subgroups and tolerating substantial inequalities in the most important segment of physical activity for health outcomes. UK activity guidelines additionally recommend that children 'minimise the amount of time spent being sedentary for extended periods' and that 'vigorous intensity activities be incorporated at least three times a week'.[39] My results provide further empirical evidence to support the findings of Richards et al.,[212] and their accompanying call to place more attention on the VPA component of guidelines to ensure health benefits. Further evidence suggests that childhood participation in sporting activities is vital to the development of fundamental motor skills, which strongly predict physical activity and weight status both in childhood and throughout adulthood.[213] To lay a foundation for lifelong activity participation it is critical that children, especially those from disadvantaged backgrounds, are provided with sufficient opportunities to develop fundamental motor skills. However, there is currently insufficient evidence concerning the most appropriate daily dose of VPA, and how to effectively promote VPA across population subgroups. Further research is needed to develop effective interventions for increasing VPA.

2.6 Conclusion

I found that the amount of VPA accumulated was socioeconomically and ethnically patterned in 7-year-old UK children, mirroring known inequalities in adiposity.[202] These findings suggest that the current central focus of physical activity guidelines, and accordingly interventions, on the promotion of aggregate measures of MVPA, may be masking behavioural differences that may have an influential role in widening inequalities in obesity between more and less advantaged subgroups. In efforts to combat rising and widening childhood obesity rates, my results suggest a need for a greater focus on the promotion of VPA in health promotion efforts, particularly for children from more disadvantaged backgrounds.

2.7 Contributions

I designed the study alongside with Esther van Sluijs. I conducted all of the analyses, interpreted the results and drafted the manuscript. Jean Adams and Andrew Atkin provided inputs on statistical models, preliminary results and full manuscript. All authors reviewed and provided into to the manuscript preceding this chapter. Lastly, Stephen Sharp at the MRC Epidemiology Unit provided statistical insights and input on the models.

3 Socioeconomic differences in the physical activity behaviour of an urban adolescent South African cohort

The final manuscript for this analysis is in circulation for submission to the *Journal of Epidemiology and Community Health.* It was conducted as part of the University of Witwatersrand-Cambridge PhD Partnership Program. Supported by the Newton Fund, this program is a collaboration between the MRC-Wits Developmental Pathways for Health Research Unit at the University of Witwatersrand Johannesburg and the MRC Epidemiology Unit at the University of Cambridge.

Based on this analysis and accompanying work in the Birth to Twenty Cohort investigating adiposity trends, I was awarded a Future Cities PhD Prize Fellowship and presented a paper titled *Urbanisation and Obesity: A case-study of Soweto South Africa,* at the Future Cities Annual Conference 'Growing Well' in Cambridge UK, July 2017.

3.1 Introduction

This chapter is the second of three epidemiological analyses exploring equity differences in the intensity patterning of children's physical activity behaviour. The preceding chapter revealed that in a high-income country context, less socioeconomically affluent children, and those from certain minority ethnicities, spend proportionally less time engaged in VPA.

Given these associations, this analysis set out to explore if socioeconomic patterning in the distribution of physical activity behaviour was present in a cohort of adolescents living in a LMIC country context. Using the Birth to Twenty Cohort (BT20), this analysis investigates if adolescents from varying levels of SEP engage in different amounts of informal activity, organised sport, physical education and active transport.

3.2 Background

Four-fifths of global premature deaths from NCDs occur in LMICs.[11] Most LMICs are experiencing health transitions whereby they are facing pandemically rising rates of obesity and associated NCDs alongside the continuation of infectious diseases and under-nutrition.[214,215] If global trends continue, 60% of the worldwide population will be overweight or obese by 2030, with a considerable amount of the burden concentrated in LMICs who are least equipped to deal with the consequences. As the burden of morbidity and mortality from obesity-related NCDs increases, global health inequities will amplify.[216,217]

With two thirds of the population now living in urban areas, South Africa is experiencing a rapid health transition with an increasingly overweight and obese population driving an escalating chronic disease burden.[218,219] The latest figures from South Africa indicate that over 30% of males and 55% of females are overweight or obese,[220] with annual rates consistently increasing within younger generations.[221] These prevalence rates rank South Africa as having one of the highest rates of obesity across the African continent. Like many LMICs, obesity was once considered a disease of affluence in South Africa, however, mounting evidence accumulated since 2000 demonstrates the clustering of obesity and associated NCDs within low income population subgroups.[153,154] There is scarce evidence and understanding of how changes in health behaviours, including physical activity, are contributing to rising rates.[222]

The vast majority of analyses investigating differences in physical activity by SEP come from high income country contexts.[223,224] There is a dearth of evidence on physical activity behaviour across LMIC populations with the commissioned Lancet Physical Activity Working Group drawing attention to a concerning evidence gap across the African continient.[87] In consideration of emerging obesity inequalities across LMICs, including South Africa, there have been accompanying calls for research on the patterning and socioeconomic determinants of physical activity behaviour.[166]

The BT20+ from Soweto, South Africa, offers a unique opportunity to investigate relationships between socioeconomic factors and physical activity, in a LMIC context, urban adolescent population. The primary aim of the analyses presented is to determine the association between SEP and physical activity behaviour (through participation in informal activity, organized sports, physical education and active transport), in adolescents from the BT20+, at 13 and 16 years of age.

3.3 Methods

3.3.1 The Birth to Twenty Cohort

All analyses presented use data from the BT20+, a longitudinal birth cohort of children born in 1990 in the metropolitan Soweto area of Johannesburg, South Africa. Originally set up to study the growth, health, well-being and educational progress of urban South African children, it is Africa's largest and longest running birth cohort.[225] The BT20+ started with the enrolment of 3,273 infants born within a seven-week period in 1990, recruited through local public health facilities. Individuals enrolled were 69% Black, 9% White, 17% Coloured and 5% Indian. Data was collected at 22 time points from antenatal to young-adulthood through interviews and assessments at local health facilities. The data collected at each assessment differed, with full details of the cohort described elsewhere.[226] The collection of both physical activity and socioeconomic asset data was only available at the follow-ups at 13 and 16 years of age.

Ethics approval for data collection was obtained from the University of the Witwatersrand Human Research Ethics Committee. Caregivers and participants provided informed consent at all data collection time points up until the participants turned 18 years of age. The analyses presented did not require additional ethical approval.

3.3.2 Physical activity

The physical activity behaviour of BT20+ participants was assessed annually from age 12-17 years through an interview administered physical activity questionnaire (PAQ) developed for South African children and adolescents. Validation studies of the PAQ against an Actical accelerometer have demonstrated good correlation, reliability and reproducibility,[227] and accordingly the questionnaire has been frequently used in South African cohorts including both children and adolescents.[228–230] The PAQ enabled the classification of behaviour into four activity domains (informal physical activity, physical education, organized sports and active travel), each quantified into total minutes per week as outlined in Table 3.1

Table 3.1 Physical activity measurement methods within the Birth to Twenty Cohort (BT20+)

Activity domain	Measurement approach
Informal physical activity	• This included the time spent engaged in any activity during school breaks or outside of school, with the exclusion of activities as part of a sports team or club. • Respondents selected three activities they most frequently participated in (from a provided list of activities common to South Africa), and outlined the time spent in each activity, each day of the week.
Physical education	• PE was defined as any organised exercise or physical activity class during school hours that was supervised by a teacher. • Participants were asked to report the number of physical activity classes they participated in at their school, across each day of the week and the duration.
Organized sports	• This was a composite measure including both club and after-school sports. • Participants were asked about weekly participation in school sport, which was defined as any extra-mural sport organized by the school (e.g. after school netball), and club sport, defined as any external or privately funded extra-mural sport (e.g. club soccer). • With an aim of representing MVPA, only sports that met a basic metabolic equivalent value of ≥3 (as referenced on the compendium of physical activity for youth)[37], were included.
Active transportation	• Active transport was pre-defined on the PAQ as walking or biking to and from school. • Since few participants reported the use of bicycles, only time spent walking for transport was included in these analyses.

3.3.3 Socioeconomic measurements

SEP was assessed at Years 13 and 16 through assessment of household assets. A range of physical assets were assessed (coded as a binary variable) and subsequently summarized to provide an overall physical assets score. Additional assets were added to the overall score at subsequent follow-up points as the distribution of ownership and wealth changed over time (e.g. ownership of a cell phone). Mothers were also asked about their occupation, medical insurance and level of education attainment.

Previous work in the BT20+ developed and assessed an overall socioeconomic index through principal component analysis including household physical assets, housing quality, house ownership and maternal education.[231] Employing a PCA approach demonstrated to be no different for ranking participants when compared to using the summed physical assets score to represent SEP, and are therefore the asset score is often used as the selected indicator of SEP in analyses of the BT20+

cohort.[232] Accordingly, the analyses presented use household physical assets as the selected proxy of SEP. Considering the different total assets summed at age 13 and 16, the asset scores at both follow-up points were scaled to a total of ten to enable comparisons.

3.3.4 Methodological approach

Two-staged hurdle models were used to investigate differences in physical activity domain participation by SEP. Models were run at the two time points (ages 13 and 16 years) where both socioeconomic and physical activity data were available, independently for each of the four physical activity domains (physical education, active travel, informal activity and organized sports). All of the models were restricted to participants with valid socioeconomic and physical activity data at both 13 and 16 years of age.

Residuals of the physical activity data demonstrated to be non-normally distributed when run in linear regression models. Two-staged Hurdle Models utilizing Generalized Linear Models (GLMs) were used in their place as they offer a solution to the issues caused by highly skewed, zero heavy distributions.[233] A GLM is an extension of linear regression models that allow the residuals to be non-normally distributed. Hurdle models analyse dependent variables through Generalized Linear Models (GLMs) separated into two categories: a binary and a non-zero generating process. Accordingly, within this analysis, the logistic model in the first stage reflects whether or not a participant reports any activity in the specific domain, while the model in the second stage investigates the non-zero data and differences in weekly duration amongst those who participate.

In the first stage, each physical activity variable was transformed into a binary variable (zero vs non-zero values), representing non-participation and participation. Each binary variable was subsequently modelled through a GLM with binomial variance and logit link functions. In the second stage, the non-zero values of each of the four physical activity domains were modelled utilizing a GLM, selected and assessed according to the most appropriate variance and link functions. Based on the nature of the physical activity data (positively skewed, discrete, continuous), four GLM models were tested and compared (across gamma & negative binomial variance and identity & log link functions) to select the most appropriate well-fitting model by each physical activity domain. The fit of models was assessed through assessing the BIC, AIC and residual deviance statistics. All models were run unadjusted and subsequently adjusted for gender and mother's age.

Given the potential for gender differences in the association between SEP and physical activity I tested for gender interactions across all models. Given the presence of significant interactions, all models were run stratified by gender.

I also ran sensitivity analyses using the additional physical activity data collected at 12, 14, 15 and 17 years to assess consistency and stability of the relationships observed at 13 and 16 over longer periods of time. A 3-year average was calculated for each physical activity domain across follow-ups 12, 13 and 14, and 15, 16 and 17, then run analogous to the two-staged hurdle models described above (using the available SEP data at ages 13 and 16, respectively).

All analyses were conducted using Stata version 15.1 (Stata Statistical Software: Release 15. StataCorp LP, College Station, TX).

3.4 Results

Of the 3,272 participants initially enrolled in the BT20+, 1,761 (53.8%) completed the assessment at Year 13, and 1,920 participants (58.6%) at Year 16. Participants without valid socioeconomic and physical activity data at both follow-up points were excluded resulting in a final analytic sample of 1,065 (due to missing data, informal physical activity and physical education were further restricted to 1,045 and 1,056 respectively). Drop-out analyses revealed no differences by gender and maternal education between the analytic (31%, N=1,065) and excluded sample (69%, N=2,207). A significantly lower proportion of the analytic sample were in private health care at birth then in the excluded sample.

All included adolescents were of Black ethnicity and 53% female, from a varied range of socioeconomic backgrounds (See Table 3.2). The physical activity characteristics of the sample are presented in

Table **3.3**. Analogous to the analytic approach these are separated into participants with zero vs non-zero values. Figure 3.2 presents this data visually across years 13 and 16, analogously split between those with zero vs non-zero data.

From age 13 to 16, the number of adolescents participating in any amount of informal physical activity, i.e. participants with non-zero values, decreased significantly (92.5% to 40.7%), with a similarly substantial decline in weekly minutes amongst adolescents reporting participation (360 to 180 minutes per week). Decreases in the proportion of adolescents participating in any organised sport were present (71.8% to 32.6%), however, the amount of weekly participation remained relatively stable (148 to 152 minutes per week). More females than males reported no participation in informal activity or organised sport at either time points. Comparatively, participation in physical education and active transport remained relatively constant across the population from age 13 to 16.

Table 3.4 demonstrates that a one unit increase in physical asset score was associated with 8% lower odds of participating in any amount of informal physical activity at age 13. For adolescents that did engage in informal activity at age 13 (N=944), each increase in physical asset score was associated with twelve minutes less informal activity per week. Significant gender interactions and subsequent subgroup analyses establishes that this social patterning in informal physical activity is driven by females in the population. Of the females that report participation, the least affluent participate in three hours more than the most affluent. These differences are no longer significant at age 16.

At both age 13 and 16, both females and males from higher SEP households are more likely to participate in any physical education classes at school then their disadvantaged counterparts, with no differences in reported duration amongst those participating. This indicates that the school that an adolescent attends (and therefore accesses physical education at) is socioeconomically patterned but once at school there are no substantial differences.

Adolescents from less affluent households were more likely to travel to school by walking than their more affluent counterparts. At age 13 a higher asset score was associated with a 33% lower odds of participating in active travel. Within those that did engage in active transport, a higher asset score was associated with twenty-two minutes less walking per week at age 13 (this is a difference of over four hours from the least to the most affluent). This relationship remained stable through to age 16.

At age 13, participation in organized sport is not socioeconomically patterned. Differences by asset score emerge and manifest significantly at age 16. Adolescents from more affluent households are more likely to participate in organized sport than their less affluent peers. Amongst those who report participation each increase in socioeconomic asset score (along a ten-point scale) is associated with five additional minutes of participation in organized sports. This amounts to a 50-minute weekly difference in organized sport participation between the most affluent and the least affluent groups across the 10-point asset score. These social differences are only significantly present in females within the population.

Supplementary analyses using the additional three-year physical activity averages across years 12-14 and 15-17 (are illustrated in A.3.1), in parallel two-stage hurdle models demonstrated similar findings (See A.3.2).

Table 3.2 Characteristics of analytic study sample: Birth to Twenty Cohort (N=1,065)

(N = 1,065) *		n (%)
Gender	Male	504 (47.3%)
	Female	561 (52.7%)
Asset score Year 13	< 2	48 (4.5%)
	2 ≥ 4	301 (28.3%)
	4 ≥ 6	370 (34.7%)
	6 ≥ 8	251 (23.6%)
	8 ≥ 10	95 (8.9%)
Asset score Year 16	< 2	38 (3.6%)
	2 ≥ 4	244 (22.9%)
	4 ≥ 6	491 (46.1%)
	6 ≥ 8	212 (19.9%)
	8 ≥ 10	80 (7.5%)

Table 3.3 Physical activity characteristics of analytic sample separated by zero and non-zero data overall, and split by gender, at follow-up points at age 13 and 16: Birth to Twenty Cohort (N=1,065)

		N- total	N-participants with zero values	N-participants with non-zero values	Median (IQR) of non-zero values
Informal activity (minutes/week)					
Age 13	Whole Cohort	1,045	101 (7.5%)	944 (92.5%)	360 (210, 600)
	Males	488	37 (7.6%)	451 (92.4%)	390 (240, 720)
	Females	557	64 (11.5%)	493 (88.5%)	305 (180, 540)
Age 16	Whole Cohort	1,045	620 (59.3%)	425 (40.7%)	180 (90, 390)
	Males	488	233 (47.7%)	255 (52.3%)	240 (120, 480)
	Females	557	387 (69.5)	170 (30.5%)	120 (60, 240)
Physical education (minutes/week)					
Age 13	Whole Cohort	1,057	729 (69.0%)	328 (31.0%)	90 (45, 135)
	Males	497	366 (73.6%)	131 (26.4%)	90 (30, 135)
	Females	560	363 (64.8%)	197 (35.2%)	90 (60, 150)
Age 16	Whole Cohort	1057	756 (71.5%)	301 (28.5%)	90 (60, 120)
	Males	497	357 (71.8%)	140 (28.2%)	90 (57.5, 135)
	Females	560	399 (71.3%)	161 (28.8%)	90 (60, 120)
Active transport via walking (minutes/week)					
Age 13	Whole Cohort	1,065	299 (28.1%)	766 (71.9%)	200 (130, 300)
	Males	504	137 (27.2%)	367 (72.8%)	200 (125, 300)
	Females	561	162 (28.9%)	399 (71.1%)	200 (150, 300)
Age 16	Whole Cohort	1,065	282 (26.5%)	783 (73.5%)	150 (100, 300)
	Males	504	111 (22.0%)	393 (78.0%)	150 (100, 250)
	Females	561	171 (30.5%)	390 (69.5%)	150 (100, 300)
Organised Sport (minutes/week)					
Age 13	Whole Cohort	1,065	300 (28.2%)	765 (71.8%)	147.7 (66.9, 348.5)
	Males	504	109 (21.6%)	395 (78.4%)	203.1 (96.9, 408.5)
	Females	561	191 (34.0%)	370 (66.0%)	101.5 (48.5, 226.2)
Age 16	Whole Cohort	1,065	718 (67.4%)	347 (32.6%)	152.3 (55.4, 332.3)
	Males	504	299 (59.3%)	205 (40.7%)	190.4 (73.8, 406.2)
	Females	561	419 (74.7%)	142 (25.3%)	102.7 (48.5, 207.7)

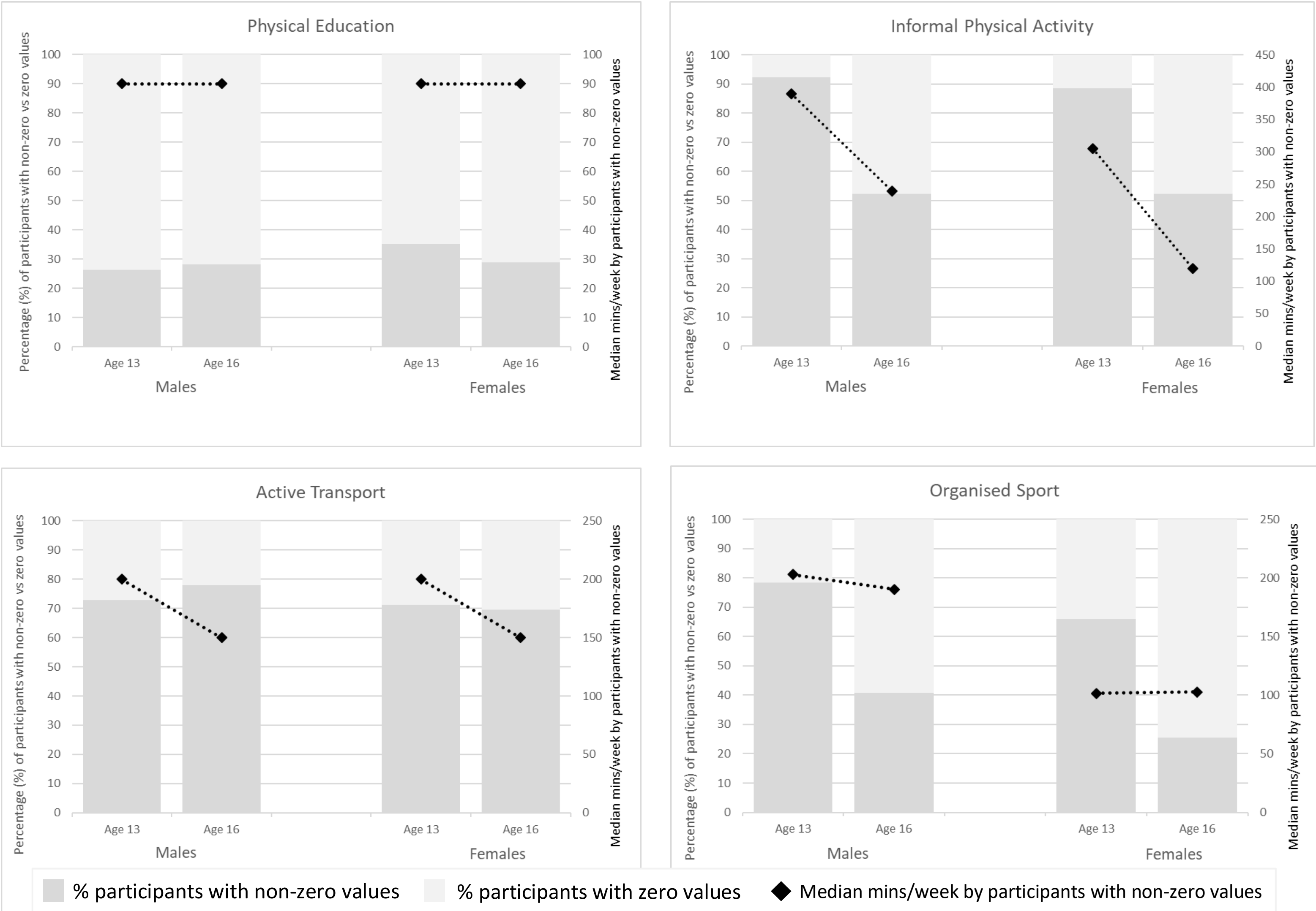


Figure 3.1 Physical activity trends of analytic sample split by participants with zero vs non-zero data: Birth to Twenty Cohort (N=1,065)

Table 3.4 Two-stage hurdle models investigating the relationship between SEP and physical activity behaviour by domain at age 13 and 16, for all participants, and by gender for females and males: Birth to Twenty Cohort (N=1,065)

		Age 13				Age 16			
	N	**Stage 1: Binary GLM**		**Stage 2: Non-Zero GLM**		**Stage 1: Binary GLM**		**Stage 2: Non-Zero GLM**	
		Odds ratio	*se*	*B-coef*	*se*	*Odds ratio*	*se*	*B-coef*	*se*
Informal Activity (mins/week)									
All participants	1,045	0.92*$	0.05	**-11.95** $**	**5.35**	1.01	0.01	2.50	3.23
Males	488	1.07	0.09	6.84	8.97	1.00	0.01	-4.80	9.66
Females	557	**0.85*** **	**0.05**	**-20.60*** **	**6.71**	1.01	0.01	3.13	3.86
Physical Education (mins/week)									
All participants	1,056	**1.08*** **	**0.04**	0.14	1.40	**1.12*** **	**0.04**	0.12	1.34
Males	497	**1.10***	**0.06**	1.19	1.88	**1.09***	0.06	0.67	1.99
Females	559	**1.06***	**0.04**	0.13	2.03	**1.14***	**0.06**	0.23	1.71
Active Transport (mins/week)									
All participants	1,065	**0.67*** **	**0.03**	**-22.57*** **	**2.20**	**0.74*** **	**0.03**	**-23.25*** **	**2.17**
Males	504	**0.69*** **	**0.04**	**-23.18*** **	**3.25**	**0.73*** **	**0.05**	**-18.51*** **	**3.32**
Females	561	**0.66*** **	**0.03**	**-22.13*** **	**2.85**	**0.75*** **	**0.04**	**-25.23*** **	**2.27**
Sport (mins/week)									
All participants	1,065	1.04	0.04	-0.36	3.17	**1.14*** **	**0.04**	**5.30**$**	**2.19**
Males	504	1.05	0.06	-0.77	5.66	1.08	0.06	2.19	5.18
Females	561	1.04	0.04	-0.67	4.01	**1.20*** **	**0.06**	**5.69** **	**2.72**

Note: .01 - ***; .05 - **; .1 - *
Significant gender interactions are indicated by a $

3.5 Discussion

This analysis reveals clear socioeconomic differences in the physical activity behaviour of adolescents living in the urban township of Soweto, South Africa. Adolescents from less affluent households spend more time walking for transport and in informal physical activities, and less time engaged in organized sport and physical education. Social differences in informal activity participation are no longer present by age 16, while social differences in organized sport participation emerge and manifest significantly with increased age across adolescence, particularly in females. Participation in each of these domains can be assumed to be associated with the accumulation of different physical activity intensities. Active travel and informal physical activity are linked to the accumulation of MPA, while organized sport is more likely to be associated with VPA.[37] Given well-established evidence that VPA is more strongly associated with reduced adiposity then MPA or LPA,[76–78,234] I suggest these differences across activity domains may have implications for widening inequalities in obesity within South African adolescents, specifically in the female population.[235]

To my knowledge this analysis is the first to investigate the relationship between physical activity and socioeconomic resources in an urban adolescent South African population. As the longest and largest population cohort of children in Africa, the BT20+ offers a unique opportunity to investigate changes in behaviour in adolescents growing up in a rapidly developing urban context. The cohort data is strengthened by detailed individual level socioeconomic data collected through one-on-one interviews with the participants at multiple follow-up points. The asset-based indicators collected as proxies of SEP are advantageous for the LMIC context in comparison to other measures as employment is often informal, temporary and transitory; income is particularly difficult to measure due to the presence of a strong informal economy and unreliable without validation from secondary sources; and measures of education can be affected by gender differences in attendance, social norms and higher numbers of individuals repeating years.[236]

The self-report physical activity data used in this analysis enabled the provision of information on the participants' engagement in various physical activity domains. While self-reporting is subject to over-reporting due to social desirability and recall bias, and potentially biased across subgroups of a population,[55] objective physical activity measurements would have not provided this domain specific information.[56] While the questionnaire used has been shown to be valid and accordingly extensively used within child and adolescent populations, these limitations remain.[227] Additionally, participants of the BT20+ were born in 1990 and thus the data presented was collected only up until 2006. While the dataset is of high value because it is the only one with this information available in South Africa, this time delay should be considered, and the findings generalised with caution to contemporary populations.

An earlier study of a sub-set of BT20+ participants at age 9 (the Bone Health Cohort) using different measurement methods, found higher levels of overall physical activity participation with a higher asset score.[228] This study in a child population is comparatively limited in its sample size and restricted in its ability to differentiate between types of physical activity behaviour. In support of my findings, a different study of rural South African adolescents (11-12 and 14-15 years of age), revealed lower household SEP was significantly associated with lower school and club organized sport participation, yet higher walking for transport.[237]

A more recent cross-sectional study of a subset of 19-20 year old young adults, recruited through the BT20+ cohort, used ActiGraph accelerometers to objectively assess physical activity patterns and examine associations with fitness and BMI.[238] The authors revealed that MPA, predominantly through walking for commuting purposes, drove participants' attainment of the global recommendations for MVPA. Similarly, to my findings this pattern was particularly pronounced in females in the population. High volumes of low-moderate intensity non-discretional physical activity has also been shown by accelerometery in a rural sample of South African children.[239]

The finding that South African children and adolescents are meeting global physical activity recommendations predominantly through moderate intensity non-discretional activity confirms research from other low-resource settings. For instance, an accelerometer study of Ugandan adolescents found that despite easily exceeding the WHO recommendations for MVPA, very little VPA was accumulated and this accordingly did not translate into cardiorespiratory fitness benefits.[212] This patterning of physical activity has also been demonstrated in a study of Nigerian adolescents.[240]

My findings add to the literature by demonstrating for the first-time social inequalities in the distribution of physical activity behaviour by individual level SEP, over-time, in a low-resource context. Considering evidence that VPA is more strongly associated with reduced adiposity and waist circumference than MPA, I suggest the socioeconomic differences in activity domain participation, and accordingly activity intensities, may have implications for widening socioeconomic inequalities in obesity rates across the South African population. The behavioural differences between socioeconomic groups of females and associated health and adiposity consequences are particularly worrisome. We need to further investigate interventions and contexts that effectively facilitate the attainment of VPA, particularly targeted at low SEP, female adolescents. Given concerning evidence from a recent study in which a sample of South

African women reporting extremely low VPA,[241] promotion and intervention efforts need to start early before patterns are entrenched for life. Recent qualitative investigations with adolescent girls in South Africa have illustrated that significant barriers to physical activity exist across seven thematic areas including poverty, body image ideals, gender, parents and home life, demographic factors, perceived health effects of physical activity and human and infrastructural resources.[242] These barriers should be considered alongside intervention development efforts. I also raise concern regarding the lower amount of physical education reported by adolescents from lower socioeconomic households. A greater understanding of school-level differences in the number and amount of physical education classes is needed.

International, and accordingly country level physical activity guidelines, focus on the assessment and promotion of overall MVPA. Based on my findings I suggest that this cumulative measure may not adequately capture significant differences in moderate vs. vigorous intensity activities that drive different health outcomes including the gender and socioeconomic adiposity differences seen in South Africa.

3.6 Conclusion

This analysis demonstrates that the physical activity behaviour of South African adolescents is socioeconomically patterned with less affluent adolescents spending more time walking for transport and in informal activity and less engaged in organised sport and physical education. As female adolescents age pronounced differences emerge with increased affluence resulting in greater organised sport participation. These activity differences mirror emerging obesity inequalities in females and lower SEP groups in the South African population. My findings suggest a crucial need for a focus on the development and promotion of higher intensity activities, particularly in less affluent females, as well as a need to ensure school-based physical education provision is equal across varying educational contexts.

3.7 Contributions

I designed this study with inputs from co-authors Shane Norris, Lisa Micklesfield, Esther van Sluijs and Jean Adams. I conducted all the analyses, critically interpreted the results and drafted the chapter. All co-authors reviewed the results and full text. Sara Hanson cleaned and managed the physical activity data. Shane Norris, Lisa Micklesfield and Sara Hanson are from the MRC-Wits Developmental Pathways for Health Research Unit at the University of Witwatersrand, Johannesburg, South Africa.

4 Socioeconomic patterning of children's accelerometer-assessed physical activity intensities and adiposity: a pooled analysis of individual-level data for 26,915 children from 36 European cohorts

This work is in preparation as a manuscript for submission to the Lancet Public Health with Esther van Sluijs, Jean Adams, Jostein Steene-Johannessen, Ulf Ekelund. The final draft will be circulated to the collaborating authors of the 36 included cohorts for input prior to submission.

4.1 Introduction

This is the final of three chapters that explore socioeconomic differences in the intensity patterning of children's physical activity behaviour. The first two chapters established that across diverse national contexts, more socioeconomically affluent children spend a greater amount of time engaged in higher intensity physical activities. Across both the UK children (MCS) and South African adolescents (BT20+), trends observed in the intensity distribution of physical activity mirror adiposity inequalities in the population.

This final analysis set out to determine if the intensity patterning of physical activity and adiposity by SEP is consistent across Europe and explore if the relationships vary by national level socioeconomic circumstances. I address this question using a large harmonised accelerometer dataset of 36 cohort studies from 16 European countries.

4.2 Background

Rates of obesity are increasing fastest within low-socioeconomic populations globally,[105] amplifying inequalities in morbidity and premature mortality across the life-course.[2] Concerningly, these differences manifest early with evidence revealing worsening socioeconomic differences in childhood overweight and obesity.[157,161] In practice, we have limited understanding of the factors driving widening socioeconomic gaps in childhood adiposity. As discussed, the evidence base for physical activity when investigated through the aggregate of MVPA does not reflect known inequalities in adiposity and health outcomes between socioeconomic groups of children.[91,92]

The two preceding two chapters illustrated distinct differences in the accumulation of physical activity and related intensities by individual SEP in UK children and South African adolescents. The lower intensity distributions performed by children of lower SEP mirror obesity inequalities across the respective populations. Other analyses in European and international cohorts support these findings in revealing VPA to act as the key factor discriminating between children who are normal versus an unhealthy weight.[243,244] No research has yet to investigate socioeconomic inequalities in VPA, MVPA and obesity within the same cohort. It furthermore is unclear if or how these associations differ between national contexts.

Global analyses suggest that countries with political and economic systems that produce greater income inequality have poorer child and adolescent health outcomes, including for NCDs.[245] It is probable that this relationship is affected by countries with greater income inequality having higher amounts of individual level deprivation.[246] We have limited understanding of whether the influence of individual SEP on physical activity intensities changes between national contexts with varying levels of economic inequality, thus differentially driving inequalities in obesity and ultimately NCDs.

Using a large international harmonised accelerometer dataset from 36 studies across 16 countries, the objective of the analyses presented is to determine if the intensity patterning of physical activity helps to explain socioeconomic inequalities in childhood obesity across Europe and investigate if individual level inequalities are driven by national level inequality.

4.3 Methods

The DEDIPAC (DEterminants of DIet and Physical ACtivity) Knowledge Hub was established in 2013 by a multidisciplinary consortium of 68 research centers from 13 European member states.[247] A central aim of the hub was the standardization and harmonization of existing European studies to describe population levels of behavior, including physical activity. The analyses presented in this chapter use data from the DEDIPAC database on children's accelerometer-assessed activity which is based at the Norwegian School of Sports Science. Data from cohort studies included within the DEDIPAC database were considered for inclusion in this analysis. Details on the development of this database are described elsewhere [242] and details of the original studies included in A.4.1. All data was stored, managed and processed following the data policies of the Norwegian School of Sports Science.

4.3.1 Selection criteria and strategy

Following initial scoping investigations of the availability of socioeconomic data within DEDIPAC cohorts, parental education (preferably maternal) was selected as the indicator of SEP. This decision was made in consideration both of evidence evaluating the reliability of measures of SEP in child and adolescent populations [248,249] and pragmatically based on data availability within the included cohorts.

Studies from the DEDIPAC children's accelerometer database were included if 1) study authors approved the use of their data for this analysis, 2) the study did not receive food industry sponsorship (in accordance with institutional policy) and 3) authors were able to provide education data on the study participant's parents (with a preference for maternal education).

Lead study authors were contacted in July 2018 with an analysis proposal requesting their participation (Included in A.4.2). Those that agreed to participate were asked to send parental education data for all included participants, using the same ID numbers as initially used when they provided data as part of the DEDIPAC consortium. Where multiple waves of follow-up were available for a cohort, inclusion was restricted to the first.

4.3.2 Data processing

4.3.2.1 Physical activity

Physical activity was assessed across all cohorts using Actigraph accelerometers. The details of physical activity data collection by individual cohort including years and months of data collection, design, accelerometer model and epoch length are outlined in A.4.3. Accelerometer data was considered daily, across 06:00 – 23:00 hours, with a minimum wear time for a valid day of 480 minutes.[250] Inclusion was restricted to participants with three or more valid days of accelerometer wear-time irrespective of weekday or weekend days.[251] Evenson cut points were used to calculate the average daily minutes spent in MPA, VPA and MVPA per day. Evenson cut points were used based on demonstrated validity and accuracy of classification among children of all ages.[252]

Values of average daily minutes of MPA were assessed and the maximum observations deemed to be within reasonable limits (99th percentile: 185 mins per day). For average daily minutes of VPA, five participants with observations above 360 minutes (6 hours) were set to 360. Alternative approaches to removing extreme values, including those outside the 99th percentile and 3.5 standard deviations, were tested and did not impact the findings.

4.3.2.2 Socioeconomic position (SEP)

Parental education was used as the selected measure of SEP. Maternal education was prioritized to combined parental measures, followed by paternal education. The operationalisation of education constructs used was prioritized as educational institutions attended/completed, qualifications attained, followed by years of education completed. Assuming the same construct, data collection via parental self-report was prioritized, followed by partner-proxy report and lastly, child report.

Parental education was harmonised into a three-level SEP variable categorized as (Low) 'up to and including completion of compulsory education', (Middle) 'some post-compulsory education or vocational training', and (High) 'completed undergraduate or postgraduate education'. Classification decisions were made based on input of the authors and by consulting standards of education within the national context of what constitutes compulsory versus post-compulsory education.[253] This harmonisation procedure is equivalent to that conducted for the International Children's Accelerometery Database with full details of the harmonisation process for each cohort outlined in A.4.4. For the remainder of the paper, low, medium and high SEP is used to refer to these three categories.

4.3.2.3 BMI

BMI z-score was used to characterise the adiposity of participants. Child anthropometric measurements (weight (kg) and height (cm)) were transformed to age and sex adjusted BMI z-scores using the WHO's Child Growth Standards 2007. Children and adolescents were subsequently categorized into weight categories representing 'normal weight', 'overweight' and 'obese' using international BMI cutoffs. BMI z-score and associated categories were calculated using extensions to the Stata egen functions zanthro and zbmicat.[201]

4.3.2.4 National inequality

The Gini coefficient was used as the selected indicator of national level inequality. The Gini index measures the income distribution within a country and the extent to which that distribution deviates from a perfectly even distribution representing absolute equality. A Gini index of 0 represents perfect equality while an index of 100 denotes complete inequality. Data outlining the Gini index of the 16 included countries was obtained through the World Bank dataset.[254]

4.3.3 Statistical Analysis

All analyses were conducted using STATA 15.1 (Statacorp, College Station, Texas, USA). Drop out analyses were conducted to determine differences between the analytic and excluded sample. Continuous summary statistics were calculated through a weighted mean by participant size.

Two-stage individual level meta-analyses were conducted using the Stata command ipdmetan.[255] This command first fits the data to the specific model for each individual study, then pools the study effects and variances into a meta-analysis model using inverse-variance weighting. In the first stage, multivariable linear regressions were fitted to analyse differences in 1) absolute mean daily minutes of VPA 2) absolute daily mean minutes of MVPA and 3) BMI z-score, across the three categories of SEP, by study. Unadjusted models were run, with adjustments sequentially tested and added. The final models are adjusted for 1) VPA: mean minutes of MPA, accelerometer wear time, age and sex, 2) MVPA: accelerometer wear time, age and sex, and 3) BMI z-score: age and sex. In the second stage, individual study estimates were pooled through a meta-analysis approach into forest plots. For each model, estimates are plotted across two forest plots using low SEP as the reference category. The first outlines the effect of low (ref cat) versus middle SEP; and the second low (ref cat) verses high SEP. Heterogeneity was assessed across all models using the I^2 statistic. By convention, I^2 values of 25% were considered low, 50% moderate and 75% high.

Unadjusted models for VPA alongside supplementary models of the comparative effect of MPA, adjusted for VPA, accelerometer wear time, age and sex, are included in A.4.5.

Subgroup meta-analyses by the Gini coefficient were pre-planned to explore differences in the socioeconomic patterning of VPA, MVPA and BMI across low, medium and high national level inequality. Given the wide range of children included in the analyses, subgroup met-analyses were also planned by age for children below and above 10 years of age.

Additionally, to visually examine differences in physical activity intensity distributions, a figure was developed presenting the proportion of VPA within overall physical activity (mins of MVPA) stratified by low, medium and high SEP.

4.4 Results

Of the 43 cohorts included in the DEDIPAC children's accelerometer database, 40 met the inclusion criteria for this study and were sent data requests. I received and successfully harmonised SEP data for 36 cohorts. Figure 4.1 outlines the flow of studies and participants at each stage, including the stepwise reasons for exclusion. From an initial pool of 39,516 participants following data harmonisation, 14% participants were excluded due to missing parental education data, while 17% did not meet the accelerometer processing criteria. 26,915 individual participants from 16 European countries were included in the final analytic sample. Less than 1% (N=200) participants were not included in the BMI meta-analysis due to missing height and weight data.

Of the 26,915 included study participants 51.7% were female and an average of 10.1 years of age. When split by BMI categories, 8.6% were underweight, 73.2% a healthy weight, 14.1% overweight and 4.1% obese. On average, participants accumulated 34.9 (Standard deviation: 16.7) minutes of MPA and 12.7 (SD: 12.5) minutes of VPA and 762.0 (SD: 121.4) minutes of wear time per day. Sociodemographic and physical activity summary characteristics of the analytic sample are outlined in Table 4.1-4.2 and included by individual cohort in A.4.6.

Drop out analyses revealed that participants in the analytic sample were more likely to be from a higher SEP, have a lower BMI z-score, be older and more likely to be female than the excluded sample.

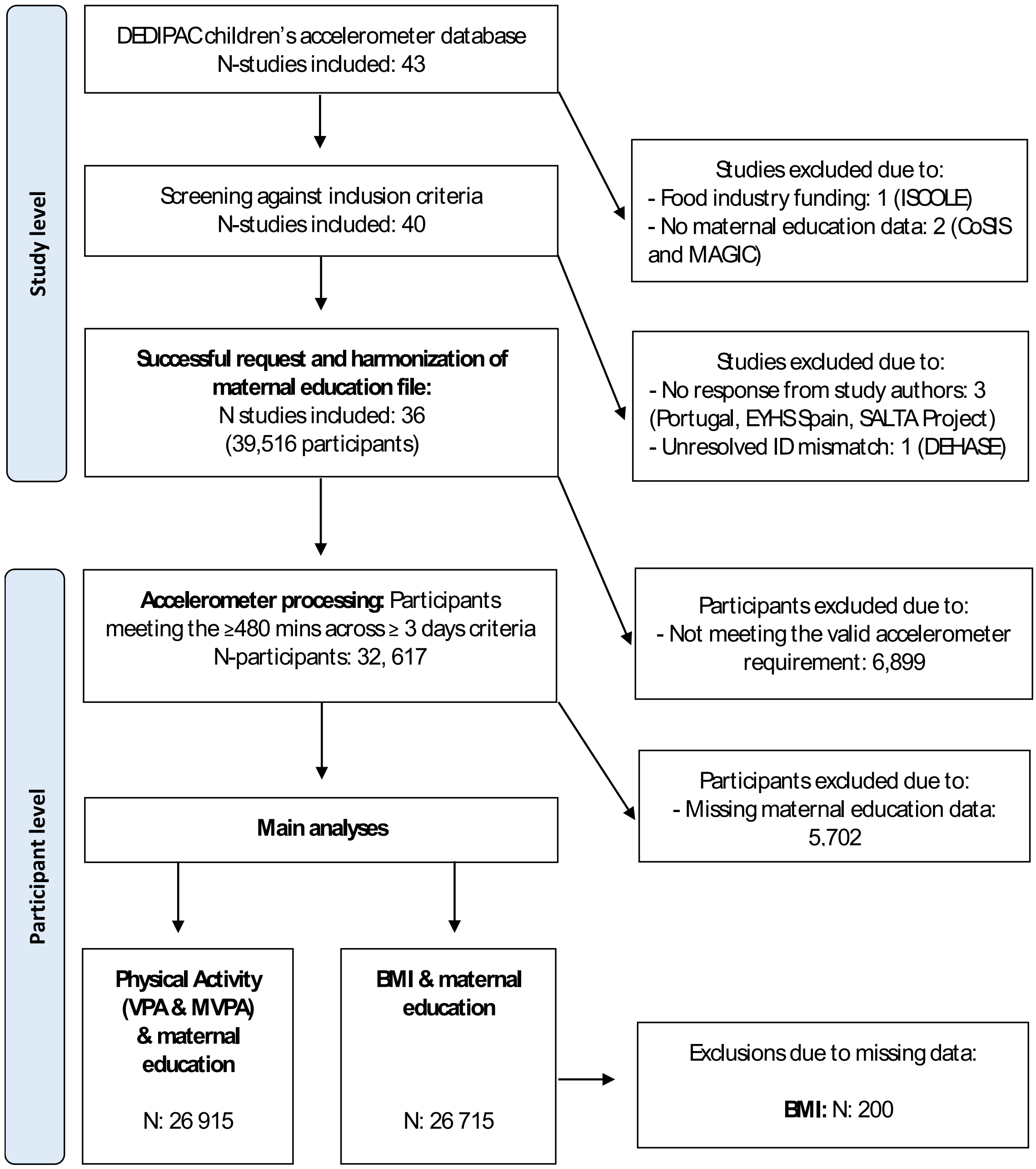


Figure 4.1 Flow chart of study and participant selection: DEDIPAC children's accelerometer and SEP database

Table 4.1 Characteristics of analytic sample, continuous variables: DEDIPAC children's accelerometer and SEP database (N=26,915 participants) [1]

	Mean (SD)
Age in years	10.1 (1.17)
Bmi z-score	0.3 (1.1)
VPA mean mins per day [2]	12.7 (12.5)
MPA mean mins per day [2]	34.9 (16.7)
Accelerometer wear time, mean mins per day [2]	762.0 (121.4)

[1] All characteristics by individual study are included in A.4.6

Table 4.2 Characteristics of analytic sample, categorical variables: DEDIPAC children's accelerometer and SEP database (N=26,915 participants) [1]

		% (N)
Gender	Males	48.3% (13,000)
	Females	51.7% (13,915)
BMI categories	Underweight	8.6% (2,288)
	Normal weight	73.2% (19,568)
	Overweight	14.1% (3,776)
	Obese	4.1% (1,083)
Socioeconomic position (SEP)	Low (Up to and including competition of compulsory education)	24.0% (6,467)
	Middle (Some post compulsory education including vocational training)	38.7% (10,427)
	High (Completed undergraduate or postgraduate education)	37.2% (10,021)

[1] All characteristics by individual study are included in A.4.6

[2] Physical activity characteristics by level of SEP are outlined in A.4.7

4.4.1 VPA, MVPA and BMI by individual level SEP

Table 4.3 and Figures 4.2 – 4.4 show the results of the meta-analyses. Significantly more minutes of daily VPA, despite lower levels of overall MVPA, were performed by higher SEP children (Low vs High SEP; VPA, 0.57 (95% CI: 0.28, 0.85); MVPA, -1.51 (95% CI: -2.36, -0.67). Figure 4.5 illustrates the differences observed between VPA and MPVA, presenting the proportion of VPA in overall MVPA, by level of activity, with participants split into three levels of SEP. This figure reveals that children from more affluent backgrounds accumulate a greater proportion of their daily MVPA from VPA, regardless of their overall activity levels. Parallel differences in adiposity were evident with lower BMI z-scores with increased SEP (Low vs High SEP, -0.20 (95% CI: -0.24, -0.16)). These relationships demonstrated stepwise increases moving from low to medium to high SEP.

4.4.2 Exploration of heterogeneity by national level inequality and age

Overall heterogeneity, assessed through the I^2 statistic, ranged from low to moderate across all models.[256] Due to the presence of moderate levels of heterogeneity, subgroup meta-analyses were conducted.

Subsequent subgroup meta-analyses by low, medium and high national level inequality revealed no substantially consistent patterning in effect estimates across VPA, MVPA and BMI z-score (See Table 4.4 and forest plots in A.4.8). The only pronounced difference across all estimates was that lower levels of MVPA with increasing individual SEP were not present in countries with low income inequality.

Subgroup meta-analyses by age revealed distinct patterning in children below and above age 10. Lower amounts of MVPA with increasing socioeconomic position manifested significantly in participants 10 years of age and older. Inequalities in VPA and bmi z-score observed became more pronounced with increasing age (See Table 4.5 and forest plots in A4.9).

Table 4.3 Summary of overall effect estimates of meta-analyses of individual participant data of multivariable linear regressions of identified variable by SEP: DEDIPAC children's accelerometer and SEP database (N=26,915)[1]

Level of SEP [2] Low SEP (reference category) vs.	**MVPA [3]** B-coefficient (95% CI)	I^2	**VPA [4]** B-coefficient (95% CI)	I^2	**BMI z-score [5]** B-coefficient (95% CI)	I^2
Medium SEP	**-1.20 (-2.02, -0.38)**	11.7%	0.12 (-0.15, 0.38)	1.7%	**-0.10 (-0.14, -0.07)**	27%
High SEP	**-1.51 (-2.36, -0.67)**	24.1%	**0.57 (0.28, 0.85)**	28.5%	**-0.20 (-0.24, -0.16)**	45.1%

[1] N-participants included in BMI z-score analysis is 26,715
[2] Low SEP: compulsory education, Medium SEP: some post-compulsory education and High SEP: undergraduate or postgraduate education
[3] Model adjusted for daily accelerometer wear time, age & sex
[4] Model adjusted for daily accelerometer wear time, moderate physical activity, age & sex
[5] Model adjusted for age & sex

Table 4.4 Summary of overall effect estimates of multivariate subgroup meta-analyses of individual participant data by low, medium and high national inequality: DEDIPAC children's accelerometer and SEP database (N=26,915) [1]

β-coefficient (95% CI) [2]		**MVPA**			**VPA**			**BMI z-score**		
Individual level of SEP	Low SEP (ref cat) vs	*Low national inequality*	*Medium national inequality*	*High national inequality*	*Low national inequality*	*Medium national inequality*	*High national inequality*	*Low national inequality*	*Medium national inequality*	*High national inequality*
	Medium SEP	-1.18 (-2.84, 0.47)	-1.43 (-3.37, 0.51)	**-1.13 (-2.21, -0.06)**	0.17 (-0.36, 0.71)	0.31 (-0.41, 1.03)	0.05 (-0.29, 0.39)	-0.04 (-0.11, 0.04)	**-0.15 (-0.23, -0.06)**	**-0.12 (-0.18, -0.07)**
	High SEP	-1.33 (-2.86, 0.20)	**-0.94 (2.97, 1.09)**	**-1.81 (-2.96, -0.64)**	**0.68 (0.12, 1.23)**	**1.17 (0.41, 1.93)**	**0.38 (0.02, 0.75)**	**-0.17 (-0.24, -0.11)**	**-0.22 (-0.31, -0.13)**	**-0.22 (-0.28, -0.16)**

[1] N-participants included in BMI z-score analysis is 26,715

[2] Forest plots for all of the estimates presented are included in A.4.8

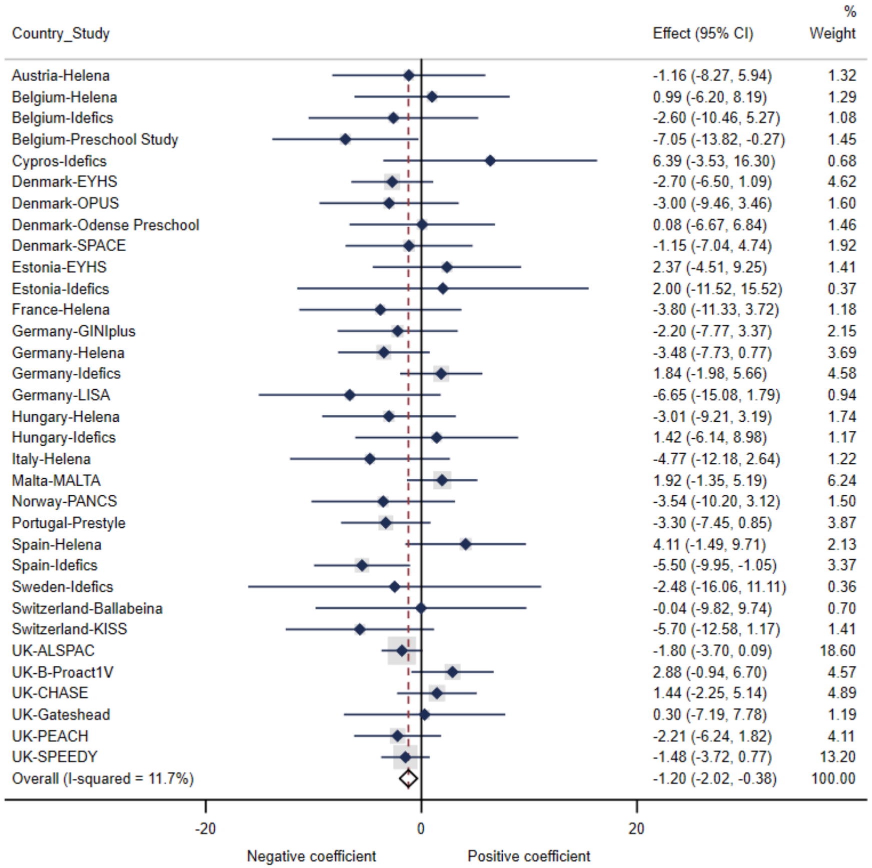
Table 4.5 Summary of overall effect estimates of multivariate subgroup meta-analyses of individual participant data split by age (under 10 years of age versus over 10 years of age): DEDIPAC children's accelerometer and SEP database (N=26,915) [1]

β-coefficient (95% CI) [2]		**MVPA**		**VPA**		**BMI z-score**	
Individual level of SEP	Low SEP (ref cat) vs	*Under 10*	*Above 10*	*Under 10*	*Above 10*	*Under 10*	*Above 10*
	Medium SEP	-0.59 (-2.06, 0.87)	**-1.50 (-2.78, -0.21)**	0.02 (-0.36, 0.41)	0.26 (-0.19, 0.71)	**-0.13 (-0.23, -0.03)**	**-0.10 (-0.17, -0.04)**
	High SEP	-0.93 (-2.84, 0.97)	**-1.83 (-2.90, -0.77)**	**0.46 (0.07, 0.86)**	**0.86 (0.24, 1.48)**	**-0.18 (-0.27, -0.09)**	**-0.22 (-0.29, -0.15)**

[1] N-participants included in BMI z-score analysis is 26,715

[2] Forest plots for all of the estimates presented are included in A.4.9

Figure 4.2 Multivariate meta-analysis of individual participant data (N=26,915) by study: Multivariable linear regressions of MVPA (mins/day) by three levels of socioeconomic position (SEP) 1) Low [reference category] vs. medium SEP, 2) Low [reference category] vs high SEP, adjusted for daily accelerometer wear time, age and sex



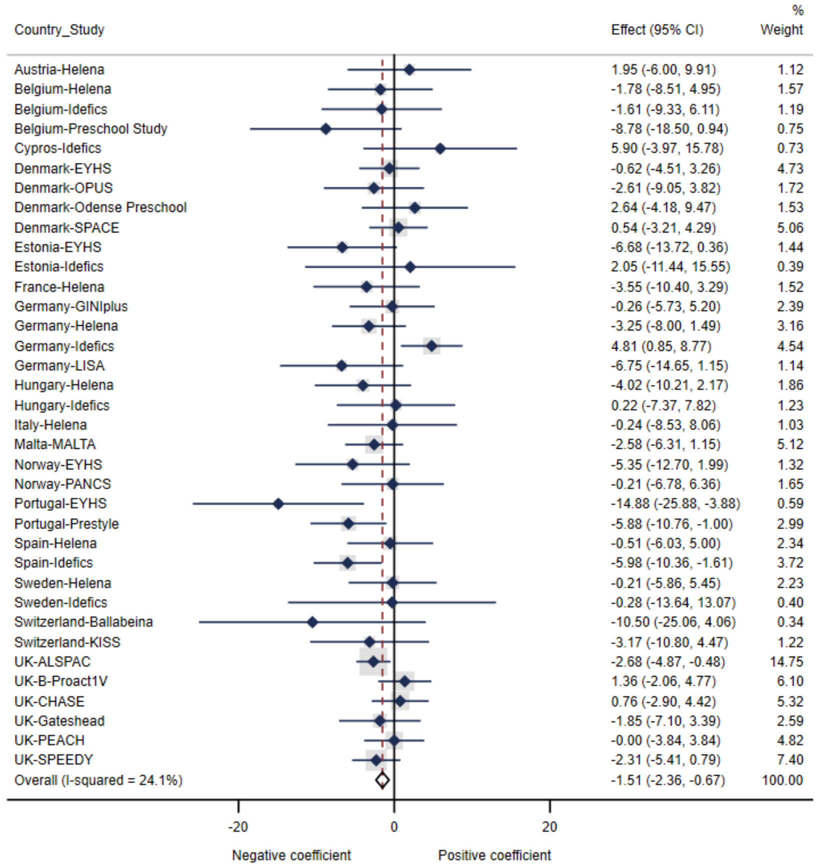
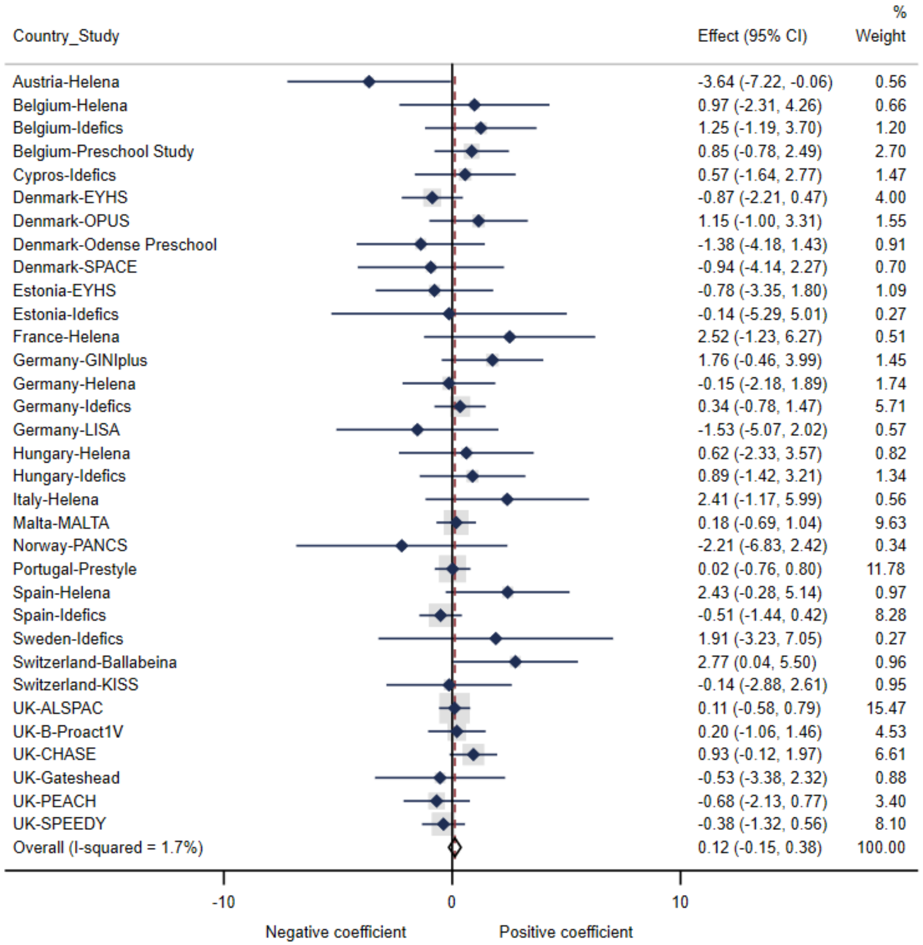


Figure 4.3 Multivariate meta-analysis of individual participant data (N=26,915) by study: Multivariable linear regressions of VPA (mins/day) by three levels of socioeconomic position (SEP) 1) Low [reference category] vs. medium SEP, 2) Low [reference category] vs high SEP adjusted for MPA, daily accelerometer wear time, age and sex



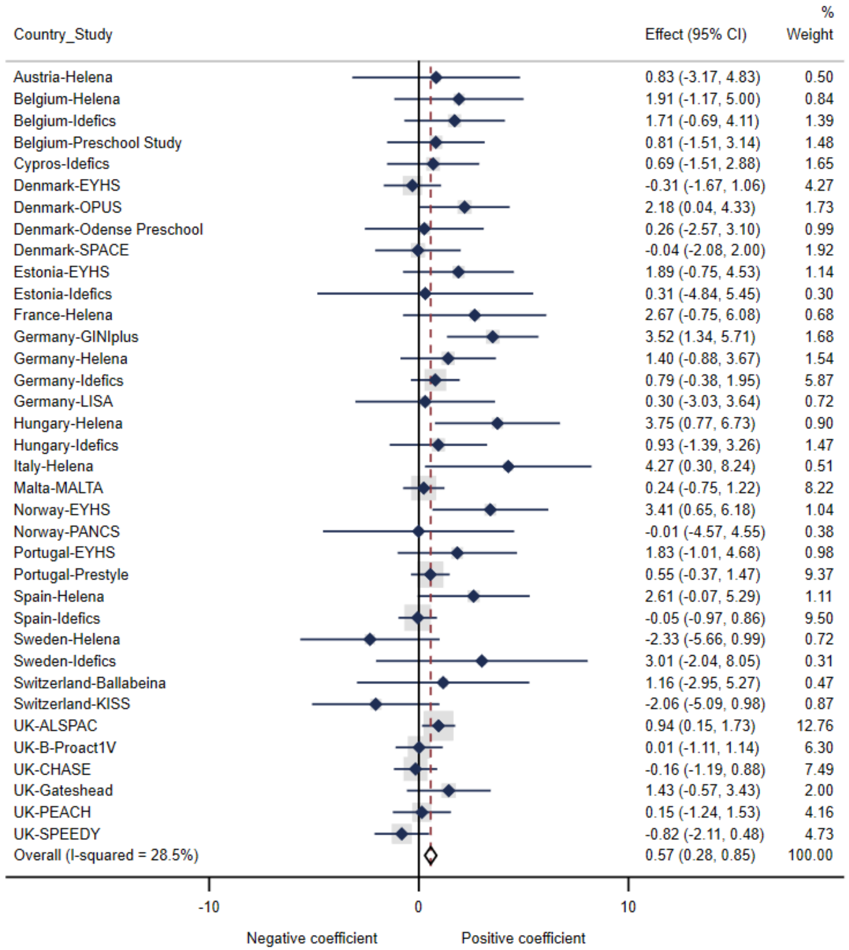


Figure 4.4 Multivariate meta-analysis of individual participant data (N=26,915) by study: Multivariable linear regressions of BMI z-score by three levels of socioeconomic position (SEP) 1) Low [reference category] vs. medium SEP, 2) Low [reference category] vs high SEP, adjusted for age and sex

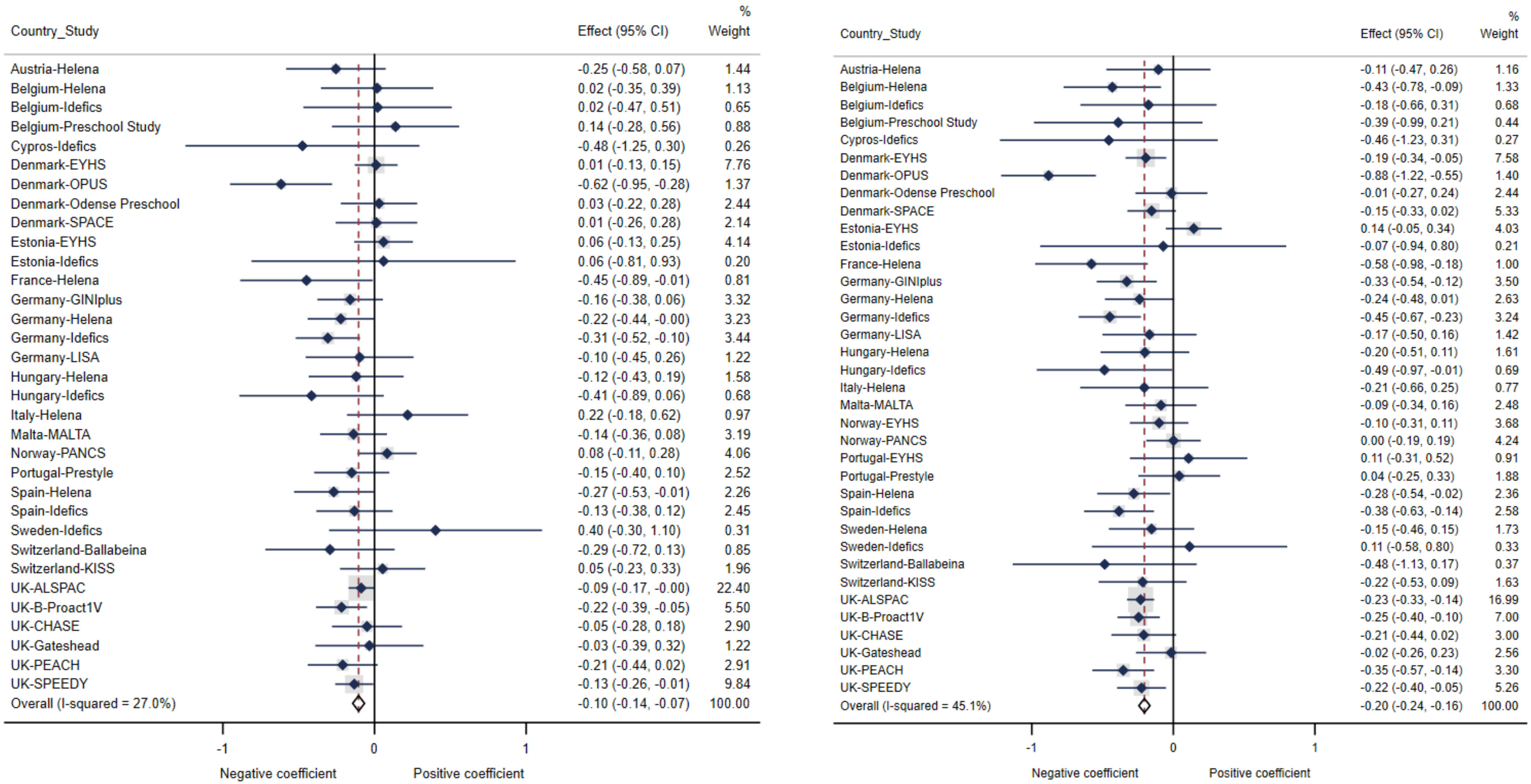
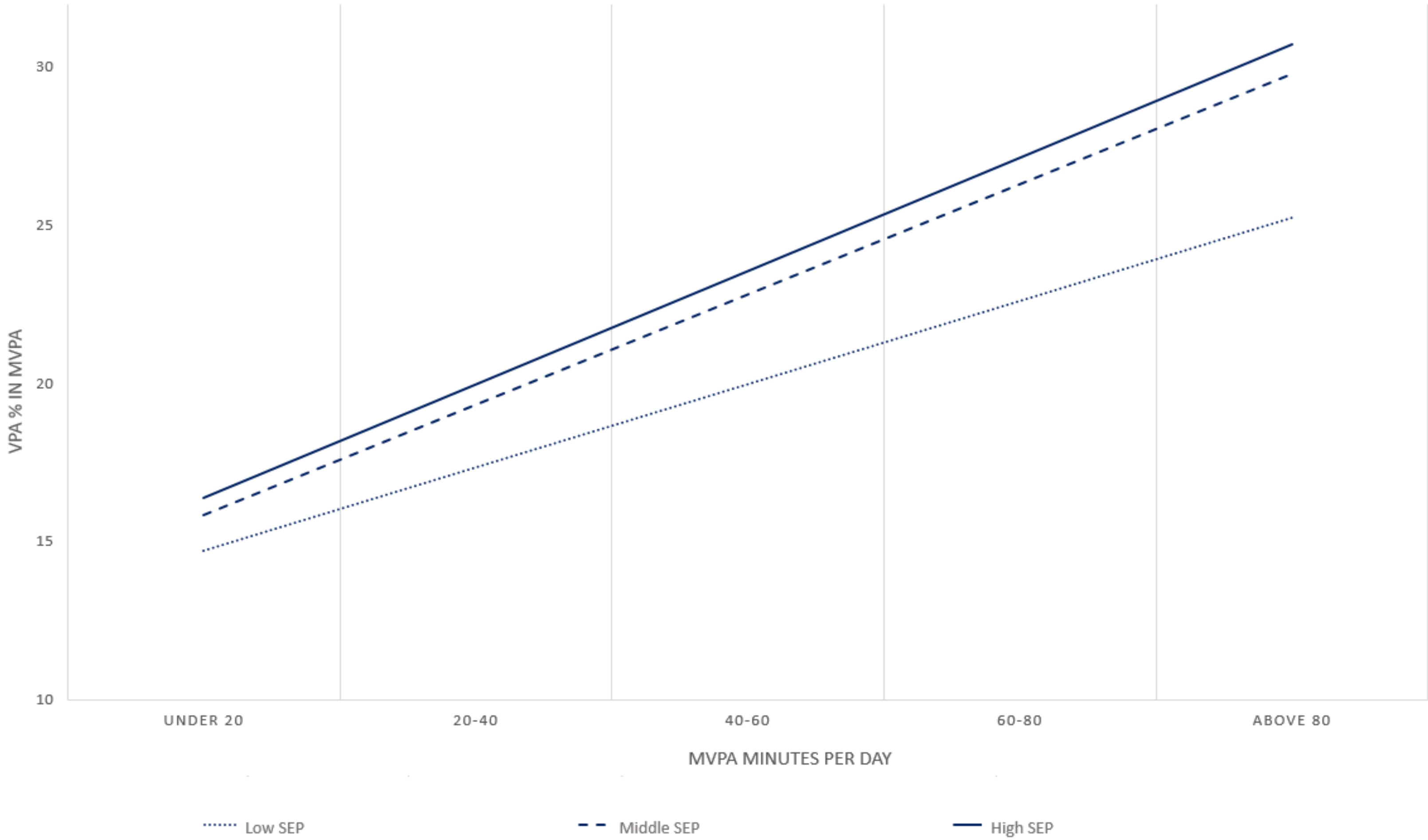


Figure 4.5 The proportion (%) of VPA within MVPA minutes per day by level of SEP: DEDIPAC children's accelerometer and SEP database (N=26,915)



4.5 Discussion

My analyses of 26,915 participants with accelerometer-assessed physical activity suggest that children with a higher SEP spend significantly more time engaged in VPA despite lower overall levels of MVPA. These differences mirror increases in BMI z-score observed in lower socioeconomic subgroups and follow a stepwise trend from low to middle to high SEP. These relationships are mostly consistent across European countries irrespective of national level inequality and become increasingly pronounced with age from childhood into adolescence.

This work substantially adds to the current knowledge base on the association between SEP and children's physical activity behaviour. Up until now the relationship between SEP and physical activity in children has been inconclusive, with a recent umbrella review concluding this is due to weak research designs and a lack of accuracy in the activity and socioeconomic assessment methods used.[166] Accelerometer measurement enables the valid and reliable assessment of physical activity across socioeconomic subgroups of children.[55] While self-reported data adds value in its provision of context specific activity information, it is challenging to accurately harmonise between national contexts due to inconsistent data collection and assessment methodologies.[257] The dataset developed for this analysis is the largest to date with both harmonised accelerometer-assessed activity and individual SEP data, both in terms of the number of children included and variety of contexts. Its inclusion of 16 countries represents the widest diversity of children's objective physical activity data combined to date across the European context. The harmonisation of parental education data across country settings to create comparable SEP categories adds further value. Through capturing knowledge-related assets, parental education is a strong predictor of children's health and enables cross-country comparisions.[146,147]

The patterning of increased VPA despite lower levels of MVPA in children from high socioeconomic backgrounds is novel as few previous analyses have investigated this relationship. While prior studies have looked at activity intensity, the majority have not accounted for MPA or investigated differences across socioeconomic subgroups.[204] The analysis included as Chapter 2 in this dissertation revealed that lower SEP children physical activity of a lower intensity, however this is restricted to the UK context. Accounting for MPA when analysing VPA is critical given differences in the accumulation and distribution of overall activity across children.

Although the differences observed are relatively small (e.g. 0.60 and 1.5 minutes per day; and 0.20 z-score units for VPA, MVPA and BMI z-score), respectively between low and high socioeconomic subgroups of children), I suggest that the trend of higher intensity activity accumulated by more affluent children despite lower levels of overall activity are relevant at a population level and have implications for the parallel trend in widening, inequalities in adiposity. This is in consideration of evidence that VPA is more strongly negatively associated with body composition and more strongly associated with cardiorespiratory fitness then MPA or MVPA, and suggestion that these benefits are attained at only 10 minutes of VPA per day.[258] Thus small improvements on a population level could result in meaningful benefit. Longitudinal analyses have demonstrated that metabolic syndrome at 36 years was independently associated with a greater shift from VPA to low intensity activity, from adolesence.[243] I further suggest that the lower levels of VPA for low SEP children are meaningful in light of recent evidence demonstrating that age-related declines in VPA are significantly greater in socioeconomically disadvantaged adolescents.[100] Considering these faster rates of age-related decline, the differences revealed in this analysis can be assumed to worsen as participants age.

The findings presented indicate that the central focus of physical activity promotion and guidelines on MVPA may be masking meaningful inequalities between socioeconomic groups. I echo prior calls for a greater focus on VPA in physical activity guidelines including more specific dose recommendations.[76] Only five of the 16 countries included in this analysis have children's physical activity guidelines that include a recommendation regarding the frequency of engaging in VPA, with only one (Denmark) specifying a dose that '*vigorous intensity activities of 20-30 minutes at least twice a week should be incorporated'*. Prior investigations in accelerometer cohorts suggest that 15 and 14 minutes per day, act as a threshold to discriminate between healthy and unhealthy children defined by the WHO classification criteria.[243,244] Further research is needed to determine the most appropriate daily dose of VPA, including consideration of what quantity is feasible for children as a target.

There are multiple reasons why the differences in VPA and MVPA may exist. Organised contexts (which are more associated with the accumulation of VPA) have been shown to result in differences in participation between more and less advantaged subgroups of children due to costs and inequalities in access.[48,183,184] These and other barriers, including time parental commitments, [259] seem to systematically influence low SEP children's access to activities that facilitate VPA.

There is an evident need for the development of programs that effectively engage children in physical activity of a sufficient intensity to accrue health benefits. While there are examples of interventions successfully improving levels of VPA,[260] these are limited in size, quality and without a focus on SEP differences between children. I highlight concerning evidence of a lack of effectiveness of school-based activity interventions across all subgroups of children (these findings are presented in chapter 6), and raise the need for the assessment and maximisation of implementation fidelity within intervention development efforts. Intervention investigations are presented in the subsequent two chapters of this thesis.

Findings from this study should be interpreted with caution in consideration of its limitations. The recruitment and sampling procedures differed between the 36 included cohorts. Some employed stratified sampling to ensure low socioeconomic groups were well represented while others did not. Similarly, the assessment methods used to measure SEP within cohorts varied between the respondent (e.g. maternal versus paternal) and the constructs assessed (e.g. educational institutions attended vs. years of education). Furthermore, it is possible that the relationship between education and access to resources is different between national contexts and accordingly influences the lived reality of the socioeconomic groups in varying manners. Given that accelerometers underestimate activity involving vertical movement (e.g. cycling) and those for which the accelerometer was not to be worn (e.g. aquatic activities or contact sports),[261] if these behaviours are socioeconomically or culturally patterned, it is possible this effected the associations observed. However, considering that organised activities are more frequent in higher SEP children and linked to VPA, if anything this mechanism would have led to an underestimation of the associations observed.[48,183,184]

4.6 Conclusion

In conclusion, this chapter illustrates differences in the intensity patterning of physical activity behaviour in children which mirror parallel inequalities in adiposity. These relationships are for the most part consistent across national settings and become more pronounced from childhood into adolescence.

My findings suggest that the focus of physical activity recommendations on MVPA may be masking important inequalities between socioeconomic groups of children. Physical activity promotion efforts should focus on providing opportunities for less affluent children to be vigorously active. Research studies and interventions are needed to determine how this can be effectively achieved.

4.7 Contributions

I designed this study in collaboration with Esther van Sluijs and Jean Adams. Jostein Steene-Johannessen and Ulf Ekelund (both from the Norwegian School of Sports Science) provided inputs to the analysis plan. Jostein Steene-Johannessen and Ulf Ekelund led the physical activity harmonisation. I collected, harmonised and merged all of the SEP data. I conducted all of the analyses at the Norwegian School of Sports Science, Oslo, Norway, where the DEDIPAC database is stored. I critically interpreted all of the results and drafted the manuscript. All of the authors listed contributed to the interpretation of the results and critically reviewed the drafted chapters. The full manuscript will now be circulated to all collaborating authors of the cohorts included before being submitted for publication.

I would like to thank the contributions of all of the authors and funders of the original studies that contributed to building the DEDIPAC accelerometer database and those that willingly provided me with additional SEP data for inclusion in this analysis.

5 Equity effects of children's physical activity interventions: a systematic scoping review

This work is published as: Love R, Adams J, van Sluijs EMF. Equity effects of children's physical activity interventions: a systematic scoping review. *International Journal of Behaviour Nutrition and Physical Activity.* 2017 ;14(1):134. doi: 10.1186/s12966-017-0586-8.

It was presented at the Annual UKCRC Health Centres Research Conference University of East Anglia, Norwich, 2016 (oral presentation) and at the International Society for Behavioural Nutrition and Physical Activity Annual Meeting, Victoria, Canada, June, 2017 (oral presentation).

5.1 Introduction

This chapter is the first of a two-part review. Through analyses across multiple national contexts the preceding three chapters revealed that socioeconomic differences exist in the intensity patterning of children's physical activity behaviour. These final two chapters set out to investigate the equity effects of children's physical activity promotion efforts across multiple domains.

The first review (this chapter) was conducted to understand what evidence was available on differential intervention effects of children's physical activity interventions across gender, BMI, SEP, ethnicity, place of residence and religion. The second (Chapter 6) is a subsequent in-depth analysis of a sub-set of interventions.

Conducted as a scoping review, this chapter investigates and summarises the availability of evidence on differential intervention effects of children's physical activity interventions across gender, BMI, SEP, ethnicity, place of residence and religion.

5.2 Background

The development of effective and sustainable interventions to increase physical activity in children has been identified by many governments and public health agencies as a key research priority for improving health outcomes.[31] However, the equity impacts of these interventions are unclear, with concern being raised regarding the possibility that even where interventions successfully improve overall behaviour across a population they also may inadvertently increase inequalities by not equally benefiting subgroups of individuals within the population.[262,263] Differential effectiveness, frequently termed 'intervention generated inequalities', ensue when interventions provide greater benefit to one population group over another.[6] Such an effect is concerning when an intervention provides greater benefit to advantaged than disadvantaged groups. Evidence from evaluations of children's physical activity interventions have revealed that inequalities are generated at multiple points throughout the intervention process including by differential provision of, and access to, interventions and resources,[174] variation in uptake,[175] differential intervention efficacy,[176,177] differential long-term compliance[178] and differential response in evaluation.[179] While these evaluations of individual trials provide an indication of the potential for equity generating effects within children's physical activity interventions, across the wider literature there is not a coherent overall understanding of the direction and size of effects across equity factors.

Despite the frequent use of systematic reviews for decision making, very few analyse or report equity effects.[264] Multiple, recent reviews have investigated the effectiveness of children's physical activity interventions across varying settings,[75,110,112,115,116,265–267] yet there is limited consideration for the differential effects of the included interventions. This has resulted in a lack of understanding of the characteristics and features of interventions that generate or reduce inequalities in children's physical activity behaviour across population subgroups. In addition, it is possible that our understanding of equity effects is biased due to underreporting of differential effects when statistical significance is not achieved. It is currently unknown whether there is sufficient consideration of differential effects across individual interventions to enable a full systematic review, and furthermore whether trials report appropriate data to allow for retrospective analysis of the question. Given this lack of clarity I conducted this review in a scoping manner to map out the existing state of the literature.

The purpose of this scoping review was to assess the availability of evidence for differential effects of children's physical activity interventions and investigate the characteristics of interventions that report differential effectiveness. The collation of evidence through this chapter will be valuable in providing an overview of the literature, with an aim of identifying where evidence gaps exist to direct future research.

5.3 Methods

A literature search was conducted to identify relevant published controlled trials designed to promote physical activity in children aged 6-18 years of age in school, community, home or health-care based settings. Searches were conducted in six electronic databases (ERIC, EMBASE, SCOPUS, PsycINFO, Medline, SPORTDiscus) in May 2016. The review protocol was registered with PROSPERO (CRD42016034020) and is included as an appendix (A.5.1). All sources were searched with a pre-piloted search strategy with no restrictions by publication year, geographic location, ethnicity or other sociodemographic indicators. Searches were limited to manuscripts available in English. The search strategy as used in Medline is included in A.5.2.

5.3.1 Inclusion criteria

The search strategy was designed to retrieve controlled trials (Study design) of single or multicomponent interventions in the school, home, health-care or community environment (Intervention), aimed at increasing school-aged children and adolescent's levels of physical activity (Population), with a minimum intervention or usual care control group (Control), and objectively assessed physical activity at baseline and follow-up (Outcome). The full inclusion and exclusion criteria are outlined in Table 5.1 below. These inclusion criteria were based on existing knowledge of the literature base demonstrating the presence of numerous controlled trials,[116] using objective forms of physical activity measurement,[115] within the population of interest.

Table 5.1 Intervention inclusion & exclusion criteria for scoping review

	Included	Excluded
Population	• Children and adolescents, 6-18 years of age at baseline	• Pre-school populations of children (5 years of age and younger) • Children selected on the basis of having a specific disease or special needs • Obese populations (95 percentile cut off point)
Intervention	• Single or multicomponent interventions aimed at increasing physical activity in the school, home or community environment	• Interventions with a duration less than 4 weeks
Study Design	• Controlled or randomised controlled trials (cluster or individual) with a minimal intervention or control group	• Trials comparing two active intervention arms
Outcomes	• Objectively measured physical activity across the whole day at baseline and follow-up (accelerometer, pedometer heart rate)	• Subjectively measured physical activity outcomes (e.g. self-report questionnaires) • Assessments where follow-up measurements are not collected in the same children • Interventions examining only part of the day activity (E.g. recess or breaktime)
Publication type	• Peer reviewed journal article	• Conference abstract, study protocol, report, dissertation, book
Publication year	• Any year	• N/A
Language	• English	• All other languages

5.3.2 Intervention screening and selection

After identifying primary article titles following de-duplication of the initial search, I manually screened and discarded those clearly outside the review criteria. The abstracts of the remaining citations that passed the initial title screening were independently reviewed and compared to the inclusion criteria to determine if retrieval of the full primary study was needed for further examination. I conducted the initial literature searches and screening stages (title, abstract). A 15% random sample was double checked at each stage by a secondary author. The full text screening was performed in duplicate by myself and a secondary author. At the full text phase, related and pre-identified reviews on the same topic were screened for missing trials.[110,112,115,116] All discrepancies were resolved through discussion amongst the research team.

5.3.3 Supplementary searches for associated publications

For each trial that met the inclusion criteria, steps were taken to retrieve all associated publications to ensure that equity analyses reported separately to the main intervention effect paper were captured. To find associated publications for each included trial, subsequent searches were performed using trial names and registration numbers. Additionally, forward citation tracking on Google Scholar was used to screen and identify additional trial publications that referenced the main effect paper included in this review.

5.3.4 Data extraction

For each trial that met the inclusion criteria, intervention characteristics and covariates were extracted using a pre-established data extraction form and Microsoft Excel. At each stage of the review process, all data was managed using Mendeley Reference Manager. Data extraction was performed in duplicate. The extracted data included trial name, journal of main intervention effect paper and year of publication, study population and size, study setting, baseline descriptive data, equity data collected at baseline, intervention type (physical activity only or multi-behaviour intervention), intervention targeting (by gender, BMI (body mass index), ethnicity, socioeconomic status (at the individual, school or community level), place of residence and religion), intervention effects across all outcomes and objectively measured physical activity, differential effect analyses and methods used to investigate differential effects (by subgroup or interaction analysis). 'Subgroup analyses' were classified as the evaluation of treatment effects by subgroups of participants defined at baseline by an equity characteristic, while 'interaction analyses' were identified as the use of an overall statistical test to directly compare differences in intervention effects across subgroups.[268]

Differential effects were considered across all factors outlined by the PROGRESS Plus framework applicable to a child population: gender, SEP, ethnicity, place of residence, and religion.[132] SEP data and analyses were further classified by whether SEP had been measured at the family, school or community level. In addition, BMI was included as an additional equity factor of particular relevance in the context of physical activity interventions in consideration of substantial evidence indicating it is patterned by SEP, geographic area and ethnicity.[159,165,269] Other factors included in the PROGRESS Plus framework (occupation, social capital, sexuality) were not considered relevant within a child population and excluded. As per standard practice for scoping reviews, methodological quality assessment of included interventions was not performed.[270]

5.3.5 Analysis

Graphical and narrative methods were used to summarize the results. Subsequently, logistic regressions analyses were performed to determine if certain intervention or study characteristics influenced the likelihood of reporting differential effects. Intervention and study characteristics of interest included as exposure variables in logistic regression models, were journal impact factor, country of origin, intervention setting, participants' ages, sample size and whether or not positive main intervention effects were reported. Outcomes comprised of whether or not any equity effects were studied, and whether or not gender equity effects were studied. No other equity characteristics were considered frequently enough to allow for further analysis. Univariable models were run for each exposure-outcome pair.

5.4 Results

Figure 5.1 outlines the search and screening process. The database search resulted in the identification and retrieval of 13,052 records, including 7,963 unique records after removal of duplicates. Following title and abstract screening, 241 potentially relevant articles were screened in full text. Ensuing assessment against the inclusion criteria led to inclusion of 125 publications representing 113 intervention trials (See A.5.3 for a table of included interventions). Citation and trial registration number searches identified an additional 92 associated publications, of which 39% had appeared in the original database search. The main trial and associated publications used are included in A.5.4-A.5.5, respectively.

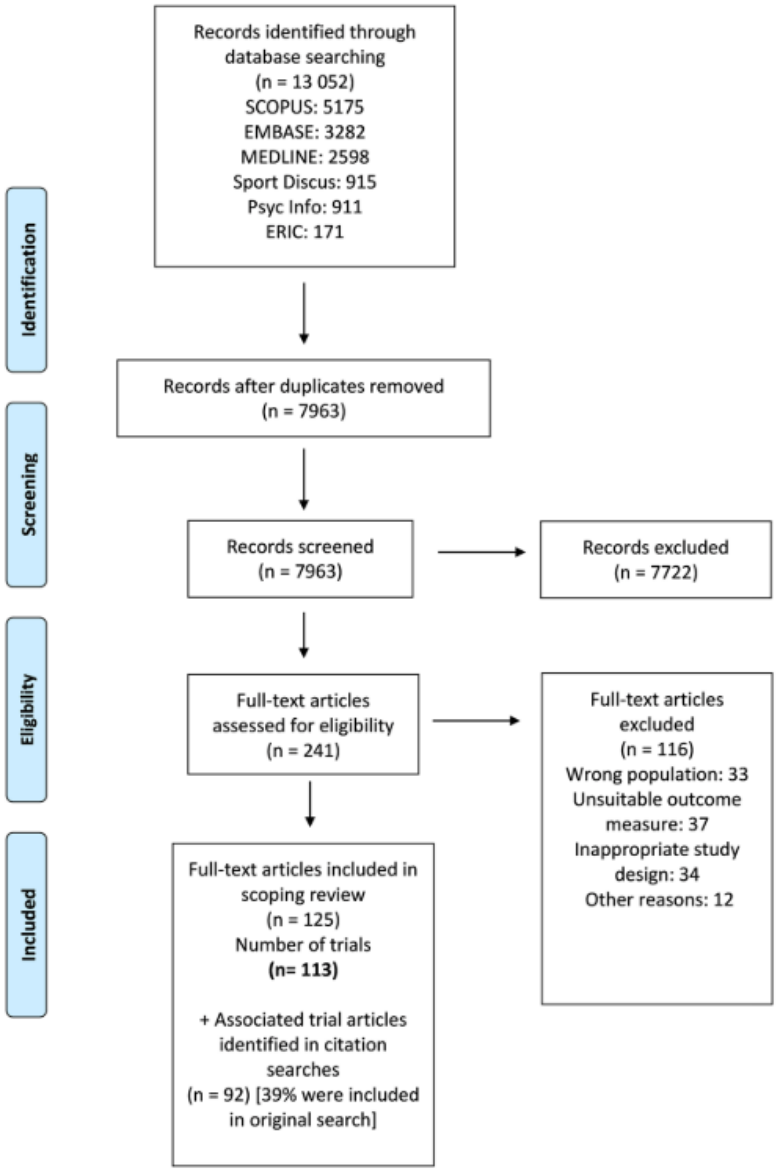


Figure 5.1 Flow chart of trial selection

5.4.1 Characteristics of included interventions

The characteristics of included trials are outlined in Table 5.2. The majority of the 113 included trials were conducted in Europe (40%), followed by North America (35%) and Australasia (20%). Of the remaining 5%, 4 were conducted in Asia and 2 in South America. Only 3 were conducted in Low and Middle Income Countries (Mexico,[271] Ecuador,[272] Turkey [273]). Forty-two percent of trials were targeted solely at physical activity behaviour change, while 58% were targeted at multiple health behaviours: primarily a combination of diet and physical activity. Of the included trials, 74% had intervention components that took place in school-based settings, 56% in home-based settings, 30% in community-based settings and 3% in healthcare-based settings.

The mean sample size of included trials was 267 (SD: 385.1), ranging widely from 18 to 3010 participants. The average age of participants at baseline ranged from 6 to 16.5 years of age, with a mean of 10.3 years (SD: 2.3). Of the 113 included interventions, 21% were targeted specifically by gender, while 19% were targeted by BMI and 17% by ethnic group. In addition, a number of interventions were targeted by school (15%) or community level SEP (17%). Of all included trials, 90% reported a positive main intervention effect on any outcome while 66% reported a positive main intervention effect on an objectively measured physical activity outcome.

Table 5.2 Characteristics of included trials (N=113)

		N (%)
Study location	Australasia	23 (20%)
	Europe	44 (39%)
	North America	40 (35%)
	Other	6 (5%)
Country income level	High-income	110 (97%)
	Low and middle income	3 (3%)
Study setting*	School-based	84 (74%)
	Community-based	34 (30%)
	Home-based	63 (56%)
	Healthcare-based	3 (3%)
Study type/behaviour	PA-only	66 (58%)
	Multi-behaviour	47 (42%)
Reported equity characteristic at baseline *	Gender	113 (100%)
	BMI	86 (76%)
	Ethnicity	60 (53%)
	SEP	60 (53%)
	Place of residence	3 (3%)
	Religion	0 (0%)
Targeted by *	Gender	24 (21%)
	BMI	22 (19%)
	Ethnicity	19 (17%)
	Individual SEP	0 (0%)
	School SEP	17 (15%)
	Community SEP	19 (17%)
	Place of residence	3 (3%)
	Religion	0 (0%)
Reported a positive main effect	By any outcome	102 (90%)
	By objectively measured physical activity	75 (66%)
		Categories marked with a * are not mutually exclusive

5.4.2 Differential effect analyses

Figure 5.2 presents the number of included trials that captured equity data at baseline, and the number that conducted equity analysis. Of the 98 interventions not targeted by gender, all reported gender data, with 45 of the 98 (46%) exploring differential effects by gender through subgroup (71%) or interaction analysis (29%). Across the remaining equity characteristics, differential effects were explored substantially less frequently. Of the 86 included interventions with reported BMI-data, 16 (19%) reported differential effects. Only 7 of the 60 (12%) trials with reported SEP data, 1 of the 49 (2%) with reported ethnicity data and 1 of the 3 (33%) with reported place of residence data documented exploration of differential effects by these characteristics. Of the 70 equity analyses reported, most were performed by subgroup analyses (74%) with considerably fewer by interaction analyses (26%).

5.4.3 Factors predicting differential analyses

Table 5.3 highlights the characteristics of differential effect analyses by each equity characteristic. Logistic regression models indicated that significantly more is known about equity in the context of school-based interventions in comparison to other contexts (home, community and health-care based) (Table 5.4). Studies investigating school-based interventions were 2.9 times (95% CI: 1.2 – 7.2) more likely to report differential effects by any factor and 4.5 times (95% CI: 1.5 – 13.2) more likely to report differential effects by gender.

As expected, due to differences in statistical power, an increase in sample size was associated with an increased odds ratio of conducting differential effect analysis (OR: 1.2, 95% CI: 1.0 – 1.4, per additional 100 participants). Country of origin (Australasia, European, North American), intervention type (targeting physical activity only or multiple behaviours), age (children or adolescents) and journal impact factor of the main trial paper were not significantly associated with reporting of differential effects.

Regression models indicated that a main intervention effect on objectively measured physical activity was associated with subsequent exploration of differential effects by equity subgroups (3.0 (95% CI: 1.3 – 6.8)). When restricted to exploration of differential effects by gender this likelihood increased to an odds ratio of 3.6 (95% CI: 1.3 – 9.5).

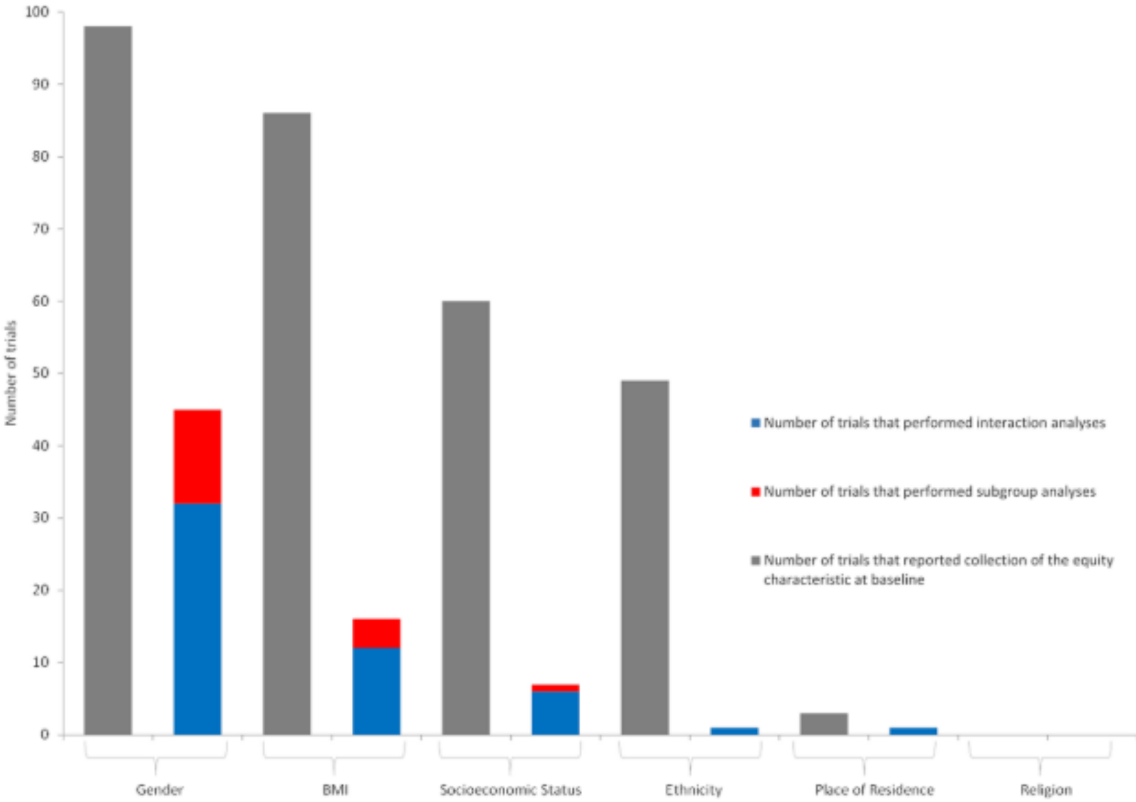


Figure 5.2 Total number of trials that reported each equity characteristic of interest at baseline and number of which reported differential analyses by subgroup and interaction analysis

Note: Trials targeted by each equity characteristic are excluded from the figure

Table 5.3 Differential analyses across all equity characteristics

	By Gender	BMI	Ethnicity	SEP	Place of residence	Religion
Total number of non-targeted studies	**98**	**113**	**102**	**113**	**112**	**113**
Conducted differential effect analyses by that characteristic	45/98 (46%)	15/113 (13%)	1/113 (1%)	7/113 (6%)	1/112 (1%)	0/113 (0%)
Location						
Australasia	6/18 (33%)	3/23 (13%)	0/23 (0%)	1/23 (4%)	0/23 (0%)	0/23 (0%)
European	25/40 (63%)	4/44 (9%)	1/43 (2%)	5/44 (11%)	1/43 (2%)	0/44 (0%)
North American	10/34 (29%)	7/40 (18%)	0/30 (0%)	1/40 (3%)	0/40 (0%)	0/40 (0%)
Other	4/6 (67%)	1/6 (17%)	0/6 (0%)	0/6 (0%)	0/6 (0%)	0/6 (0%)
Publication year						
2004 & earlier	2/6 (33%)	0/8 (0%)	0/4 (0%)	0/8 (0%)	0/8 (0%)	0/8 (0%)
2005 – 2009	10/18 (56%)	2/21 (10%)	0/21 (0%)	0/21 (0%)	0/21 (0%)	0/21 (0%)
2010 – 2014	25/54 (46%)	12/63 (19%)	1/57 (2%)	6/63 (10%)	0/62 (0%)	0/63 (0%)
2015 & above	9/20 (45%)	1/21 (5%)	0/20 (0%)	1/21 (5%)	1/21 (5%)	0/21 (0%)
Physical activity only or multi-behaviour intervention						
Physical activity only	27/58 (47%)	7/66 (11%)	0/64 (0%)	2/66 (3%)	1/46 (2%)	0/66 (0%)
Multi-behaviour	19/40 (48%)	8/47 (17%)	1/37 (3%)	5/47 (11%)	0/66 (0%)	0/47 (0%)
Intervention setting						
Home based	23/55 (42%)	8/63 (13%)	0/54 (0%)	5/63 (8%)	1/62 (2%)	0/63 (0%)
School based	41/74 (55%)	11/84 (13%)	1/78 (1%)	6/84 (7%)	1/83 (1%)	0/84 (0%)
Community based	12/28 (43%)	6/34 (18%)	0/29 (0%)	2/34 (6%)	1/33 (3%)	0/34 (0%)
Health-care based	3/3 (100%)	0/3 (0%)	0/3 (0%)	0/3 (0%)	0/3 (0%)	0/3 (0%)
Main intervention effect, any outcome						
Main effect	46/90 (51%)	12/102 (12%)	1/92 (1%)	6/102 (6%)	1/101 (1%)	0/102 (0%)
No main effect	0/8 (0%)	3/11 (27%)	0/10 (0%)	1/11 (9%)	0/11 (0%)	0/11 (0%)
Main intervention effect, objectively measured physical activity						
Main effect	39/70 (56%)	10/75 (13%)	1/71 (1%)	5/75 (7%)	0/74 (0%)	0/75 (0%)
No main effect	7/21 (33%)	5/38 (13%)	0/31 (0%)	2/38 (5%)	1/38 (3%)	0/38 (0%)

Note: Denominators are not consistent as each row is restricted to the number of non-targeted trials, separated by each equity characteristic

Table 5.4 Logistic regression models exploring factors predicting analysis of differential effects

	OR (95% confidence interval) of reporting differential effects by any equity characteristic (n = 113)	OR (95% confidence interval) of reporting differential effects by gender (n=98)
Australasia vs all others	0.4 (0.1 – 2.1)	0.2 (0.0 – 1.8)
European vs all others	1.1 (0.2 -5.8)	0.8 (0.1 – 5.1)
North American vs all others	0.4 (0.1 – 2.1)	0.2 (0.0– 1.3)
Physical activity only (1) or multi-behaviour intervention (0)	0.7 (0.3 – 1.5)	1.1 (0.5 – 2.4)
Home based vs all others	0.6 (0.3 – 1.4)	0.6 (0.3 – 1.3)
School based vs all others	**2.9 (1.2 – 7.2)**	**4.5 (1.5 -13.2)**
Community based vs all others	0.9 (0.4 – 2.0)	0.8 (0.3 – 2.0)
Health-care based vs all others	Not enough variation to run	Not enough variation to run
Age (Child under 12 (0), Adolescent 13-18 (1))	1.4 (0.6 – 3.2)	1.6 (0.6 – 4.2)
Sample Size (Per increase in 100 participants)	**1.2 (1.0 – 1.4)**	**1.2 (1.0 – 1.4)**
Journal Impact Factor	1.1 (0.9 – 1.3)	1.1 (0.9 – 1.2)
Reported a main intervention effect on any outcome	2.5 (0.6 - 9.8)	Not enough variation to run
Reported a main intervention effect on objectively measured physical activity	**3.0 (1.3 – 6.8)**	**3.6 (1.3 – 9.5)**

5.1 Discussion

To the best of my knowledge, this is the first review to provide a comprehensive overview of available evidence of equity effects in the children's physical activity literature. Overall, the review reveals a scarcity of consideration for equity. Despite all included trials collecting at least one equity characteristic of interest at baseline, a limited number reported investigating analyses of differential effectiveness (46%). When reported, differential effect analyses were primarily concentrated on gender, with substantially fewer focusing on BMI, SEP, ethnicity, place of residence or religion. The failure of authors to report equity analyses (despite having data available with which to do this) reflects a lack of understanding of, and importance given to, intervention generated inequalities.

The wider health literature supports these findings, with review analyses of both smoking interventions and universal school-based behavioural interventions indicating similar rates of equity analyses, with accompanying calls for more routine testing of differential effects.[274,275] Similar to these results, analyses within the adult physical activity intervention literature have found that despite researchers commonly measuring equity characteristics at baseline, differential effect analyses are infrequently reported in trial evaluations.[276,277] Likewise, when reported, analyses are mostly confined to gender, with considerably less attention given to other equity characteristics.

The lack of equity focus identified in this review is surprising considering the widespread public health policy focus on inequality.[264,278,279] Despite overarching policy goals, in practice we have a very limited understanding of the potential for inequality generating effects from current intervention efforts. As a research community we are not accumulating the evidence policy makers need to deliver on objectives and targets for the development and implementation of interventions that effectively reduce health inequalities.[280,281]

Considering the state of the evidence and paucity of data, I recommend and echo prior calls for the conduct and reporting of differential effect analyses.[277] However, I acknowledge the financial and resource requirements of running sufficiently large trials powered to detect a main intervention effect, let alone differential effects between subgroups. To tackle these critical questions, I encourage both a continued effort towards high-quality, large trials, adequately powered to address questions of differential effectiveness alongside the pooling of outcome data in systematic reviews. Continuing to amass evidence solely to address the question of overall effectiveness will only propagate our current level of understanding and limit the evidence base from progressing.

I acknowledge the potential generation of false negative results as a consequence of subgroup and interaction analyses with inadequate statistical power.[282–284] While it is encouraging that included interventions with a larger sample size were more likely to perform differential effect analyses, I do not specifically know what proportion of the 70 differential effect analyses (74% by interaction and 26% by subgroup analysis) were adequately powered. Considering that many trials focus on recruiting sufficient participants to detect differences in effect between intervention arms,[285] it is crucial that each analysis is interpreted sensibly, and the credibility of the analyses carefully scrutinized independently against established criteria.[268,286–288] Guidelines generally advise conducting a small number of differential effect analyses, that are pre-specified and based on strong theory, adjustment for multiple testing is considered, and that reporting indicates if analyses were pre-planned or performed post-hoc. Unfortunately, previous evidence has indicated that differential effect investigations by subgroup analyses are often not pre-specified in protocols, and even when they are, 90% deviate from the described plan.[289] Considering the possibility that reporting of differential effect analyses is dependent on the achievement of statistical significance at a $p \leq 0.05$ level, we need to continue moving towards required pre-specification in protocols and analyses plans, and the enforcement of reporting of any deviations and accompanying rationales in trial publications by reviewers and journals.

Alongside this evidence is the proposition that authors may be particularly likely to explore subgroup analyses if they did not find a main intervention effect.[290] Encouragingly, this hypothesis was not supported within this review, with trials that found a main intervention effect being significantly more likely to conduct differential effect analyses in comparison to those that did not.

Girls are well known to be on average less active then boys.[210,291] This observation is likely influencing the focus on assessment of differential intervention effects by gender. Moreover, compared to gender, SEP is challenging to accurately measure within populations of children and adolescents. Evidence has shown difficulties in the conceptualization of SEP, and inconsistencies in the relevance of tangible measures of education, occupation and income in relation to children's perceived SEP.[292] Additionally, when parental questionnaires are utilized to help overcome these differences, new challenges arise. Evaluations indicate that the completion of parental questionnaires and consent forms is socioeconomically patterned with factors including poor literacy levels among low income parents affecting the return of signed consent forms.[293] Furthermore, gender is generally equally distributed across participant samples and study groups. In comparison, ethnicity and SEP often end up considerably skewed towards the majority within that specific context, since intervention trials are frequently implemented within a restricted region of schools and neighbourhoods. These differences in distributions may result in an increased likelihood of gender being adequately powered for differential effect analyses in comparison to the remaining equity characteristics. It is likely that these issues contribute to the differences and patterns identified in these analyses.

There is growing evidence that certain subgroups such as girls, children with disabilities, and those from minority ethnic groups and low SEP families or neighbourhoods have lower levels of physical activity than their counterparts.[170,210,294–299] These lower physical activity levels subsequently contribute to associated and apparent health inequalities.[123] In response, a multitude of interventions tailored to the characteristics of high-risk subgroups have been developed,[112] as evidenced in this review with more than a third of included trials targeted by at least one equity factor and a subset of these targeted by multiple equity characteristics. The comparative effectiveness of targeted vs. non-targeted interventions is largely unknown as the interventions evaluated differ substantially. Although subgroups of high-risk children may benefit from an intervention targeted directly at them, public health benefits in terms of physical activity and health outcomes may be limited in the absence of a population approach. Rose's theory of disease prevention suggests that it is more efficient to utilize a universal approach that works to shift the entire population distribution of a risk factor than to focus exclusively on a high-risk subgroup through a targeted intervention.[101] Analyses of differential effects in response to one universal intervention revealed greater benefits to girls and inactive children, but also significant benefits to boys and those already active.[300] This suggests that a gender-targeted approach in this case may have disregarded a subgroup also able to benefit. While it is likely that the optimum population preventative strategy incorporates a tiered combination of both targeted and universal approaches, the optimal balance for the greatest impact on behaviours and disease risk at maximal cost-effectiveness is unclear. Given this state of the evidence, we highlight the concurrent need for research on the comparative effectiveness of interventions targeted specifically at population subgroups and those that are universally targeted. It is critical to understand the comparative effectiveness (i.e. behaviour change in girls within a female targeted vs a universal intervention) while considering the lack of effect within the non-targeted subgroup (i.e. loss of any effect in boys from the dissemination of a female targeted intervention).

This scoping review has multiple strengths, including the systematic searches, duplicate review methods, and the consideration of a wide range of evidence. As is inherent within a review, this work is limited by reporting and the quality within the included primary studies. Due to the nature of the review as a scoping exercise to map out available evidence, I did not look at the reporting and analysis of interaction and subgroup effects in a detailed manner. I also recognize the limitations inherent in combining a heterogeneous set of intervention studies with varying aims and implemented across a variety of settings. I further acknowledge the intrinsic challenges in the use of SEP, due to the fact it is measured at multiple levels (individual, home, community SEP), with each captured by numerous indicators (parental education/occupation, asset-based indicators, free-school meals). As appropriate for a scoping review, I am unable to draw conclusions regarding the extent of differential effectiveness in children's physical activity promotion efforts. However, the results indicate that there may be sufficient data available (published and unpublished) for a more in-depth exploration of differential effectiveness, either through meta-analyses or pooling of primary data. This may need to be performed within a more homogeneous subset of studies, and take the operationalization of varying indicators into consideration.

5.2 Conclusion

There is a widespread lack of knowledge of the equity effects of children's physical activity interventions. Despite often collecting relevant information at baseline, most controlled trials do not report analyses of differences in intervention effect. More evidence is needed to effectively understand how current intervention efforts are affecting existing behavioural inequalities across population subgroups of children, while being mindful of the tension with statistical constraints. Understanding the characteristics of interventions that generate differential effects has important implications for directing future research and the development of interventions. As governments and international health organizations increasingly advocate the need for equity focused evidence to inform population interventions addressing health inequalities, there needs to be action to ensure that intervention evaluations and systematic reviews consider and address these equity effects.

5.3 Contributions

I designed this study with Esther van Sluijs and Jean Adams. I conducted the literature searches in each of the identified databases. I conducted the title, abstract and full text screening in duplicate with Esther van Sluijs, and the data extraction in duplicate with Jean Adams. I ran all of the statistical analyses, critically interpreted the findings and drafted the full manuscript. Esther van Sluijs and Jean Adams contributed to the interpretation of the results and provided inputs to the final manuscript. Additionally, Isla Kuhn, from the University of Cambridge Medical Library, provided advice on the literature searches.

6 ARE SCHOOL-BASED PHYSICAL ACTIVITY INTERVENTIONS EFFECTIVE AND EQUITABLE? A META-ANALYSIS OF CLUSTER RANDOMIZED CONTROLLED TRIALS WITH ACCELEROMETER-ASSESSED ACTIVITY

This work is published as: Love R, Adams J, van Sluijs EM (2018). Are school-based physical activity interventions effective and equitable? A systematic review and meta-analysis of cluster randomized controlled trials with accelerometer-assessed daily physical activity. *Obesity Reviews*. 2019:1-12. doi:10.1111/obr.12823.

It was presented at: the Lancet Public Health Science Conference, Queen's University Belfast, November 23rd, 2018 (poster presentation) and at the International Society for Behavioural Nutrition and Physical Activity Annual Meeting, June 2018, Hong Kong (Both as a poster and as the central presented component of a invited PhD Keynote Talk).

6.1 Introduction

This chapter is the second of a two-part review included in this thesis. The preceding chapter assessed and summarized the availability of evidence on equity effects in response to children's physical activity interventions across gender, BMI, SEP, ethnicity, place of residence and religion. The aggregated data revealed that despite regularly collecting relevant information on gender and SEP at baseline, many controlled trials do not report analyses of differences in effects across equity characteristics. This chapter, through the utilization of unpublished data (attained through author requests), set out to determine the overall effectiveness of school-based physical activity interventions and investigate if the observed effect varies by gender or SEP.

6.2 Background

Governments worldwide are prioritizing obesity prevention and health equity promotion through, amongst other things, increasing physical activity in young people.[31] As schools offer a context to reach the majority of young people irrespective of background characteristics, they provide an obvious intervention setting. However, evidence for the effectiveness of school-based physical activity interventions is mixed,[301] with positive effects proving challenging to maintain over the long-term.[265] Furthermore, it is unclear whether population subgroups benefit equally from current efforts. There is theoretical and empirical evidence that public health interventions can exacerbate existing inequalities via differential effects between population subgroups.[173] Inequitable effects have been demonstrated in some school-based physical activity interventions,[176] but there is an overall scarcity of evidence on this possibility.[302] Even a null effect overall may mask differential effects between population subgroups.

Much early evidence on school-based physical activity interventions showed positive effects, but used self-report measures,[110,112] which have limited validity and differential bias across population subgroups.[47] While more recent reviews are restricted to objective measures, they commonly combine data from a variety of tools (e.g. accelerometers and pedometers),[303] measurement periods (e.g. recess only and whole day) and outcomes (e.g. MVPA and average activity intensity).[115,118] The potential impact of this is exemplified by one trial in which the effect estimate on accelerometer-assessed physical activity during school (when children were directly exposed to the intervention) was more than four times higher than the effect across the full day (z-scores: 0.92 vs. 0.21, respectively).[304] Given that most school-based interventions are designed to affect total activity across the day, and that total MVPA is most strongly associated with different health benefits,[305] the most rigorous evaluation of the overall and equitable impact of school-based physical activity interventions requires a focus on whole day MVPA.

The scoping review I presented in chapter 5 revealed an overall scarcity of published evidence on the equity effects of children's physical activity interventions. However, it identified that substantial relevant unpublished data was available – particularly in terms of gender and SEP, most substantially in relation to school-based interventions. The objective of this subsequent review was to systematically review and meta-analyse data on the overall effectiveness of school-based physical activity interventions on accelerometer-assessed daily minutes of MVPA, and to investigate if this effect varies by gender or SEP.

6.3 Methods

This systematic review and meta-analysis is reported according to the PRISMA guidelines. The protocol was registered with PROSPERO (CRD42017062565) and is included in A.6.1.

6.3.1 Search strategy and selection criteria

The literature search was conducted in six electronic databases (ERIC, EMBASE, OVID MEDLINE, PsycINFO, Scopus, SPORTDiscus), originally in May 2016 (for the scoping review included in chapter 5) and updated for the current review in February 2017 (identified 1,427 additional publications for screening). The search aimed to identify controlled trials of physical activity promotion in young people that used objective measures of physical activity. The search strategies were pre-piloted with no restrictions by publication year, geographic location, or other sociodemographic indicators (See A.6.2).A.5.2 Medline Search Strategy

In order to focus on a homogeneous pool of trials and enable in-depth exploration of equity effects, and based on the assessment of data availability, the inclusion criteria from the scoping review were made more restrictive for the current review. We limited inclusion to interventions conducted in schools (84/113 trials included in scoping review), and to cluster-randomised (at the school or classroom level) controlled trials which used accelerometers to assess activity across the whole day. The full inclusion criteria are outlined in Table 6.1.

Table 6.1 Study inclusion and exclusion criteria for systematic review and meta-analysis of school-based physical activity interventions

	Included	Excluded
Population	- School-aged children and adolescents, 6-18 years of age at baseline	- Pre-school populations of children (5 years of age and younger) - Children selected on the basis of having a specific disease or special needs - Obese populations (95 percentile cut off point)
Intervention	- School-based single or multicomponent interventions of at least 4 weeks duration aimed at increasing physical activity	- Interventions with a duration less than 4 weeks - Interventions implemented solely within community and home environments
Study Design	- Cluster-randomised (at the classroom or school level) controlled trials	- Interventions randomised at the individual level - Interventions described as pilot or feasibility studies
Comparator	- Trials with a minimal intervention or no intervention comparison group	- Trials comparing two active intervention arms
Outcomes	- Acclerometery-assessed physical activity across the whole day at baseline and follow-up, in the same participants	- Subjectively measured physical activity outcomes (e.g. self-report questionnaires) - Non-accelerometer forms of objective physical activity outcomes (e.g. pedometers and heart rate) - Physical activity outcome data not collected in the same children at baseline and follow up - Physical activity outcomes examining only part of the day activity (E.g. recess or breaktime)
Publication type	- Peer reviewed journal article	- Conference abstract, study protocol, report, dissertation, book
Publication year	- Any year	- N/A
Language	- English	- All other languages

Following de-duplication, the title and abstract screening removed papers clearly outside of the scoping review inclusion criteria. The selection was performed by one reviewer, with a 15% random sample double checked by a second reviewer (Coder agreement rate was 98%). Full text screening was performed independently by the same two reviewers. All discrepancies were resolved through discussion.

Intervention characteristics were extracted from included trials using a pre-piloted data extraction form. Data extraction was performed in duplicate by two reviewers, and included baseline descriptives, study name and design, intervention and outcome characteristics, reported intervention main effect, and effects across gender and SEP (see A.6.3 for a complete list of items).

Quality assessment was performed independently by two reviewers using the Cochrane Collaboration's risk of bias tool. Studies were assessed across each of the five domains of bias (selection, performance, attrition, detection and reporting) and classified as presenting a low, high or unclear risk of bias. In the case of disagreement on data extraction or quality assessment, consensus was determined by consulting a third reviewer.

None of the included trials reported sufficient relevant data for the planned analyses, and thus all authors were contacted to obtain further information. Corresponding authors of the main trial publications were contacted in May 2017 by email. Data request forms were pre-completed as far as possible from the published papers and authors were requested to further complete these. Requested data included sample size (N), mean and standard deviation (SD) of daily minutes of MVPA at baseline and all follow-ups for both intervention and control groups, for the main intervention effect, and stratified both by gender, and SEP. If possible, I requested that SEP was categorized into three groups (low, middle and high, as defined by the author). Where this was not possible, two groups representing low and high SEP were accepted. As there are many possible measures of SEP, we provided authors with a preference hierarchy: (1) parental education (maternal preferable to paternal), (2) area-based markers of deprivation (e.g. Index of Multiple Deprivation or postal code-based indices), and (3) household income equivalized for household composition. This hierarchy was developed based on research evaluating the validity of measures of SEP in child and adolescent populations.[248,249] The full request details and data extraction form is included in A.6.4.

6.3.2 Data analysis

To assess overall and differential intervention effects on MVPA, mean change scores from baseline to follow-up were calculated for the intervention and control groups. For each analysis the post-intervention follow-up time closest to the intervention end point was utilized. Intervention effects were calculated by dividing the between group difference of mean change in minutes of MVPA from baseline by the pooled SD of change in MVPA for the intervention and control group, assuming a correlation of r=0.5 between baseline and follow-up (See A.6.5 for full formula).[306]

Effect sizes were calculated using Hedges G and utilized in meta-analyses. I chose random effects meta-analyses based on the expectation of heterogeneity given the differences in study populations and interventions. Differences in effect by gender and SEP were tested statistically by performing meta-regressions on the stratifying variable in a meta-analysis model pooling the individual subgroups for that characteristic.

Statistical heterogeneity was assessed visually using forest plots and quantified using the χ^2 and I^2 statistics. By convention, I^2 values of 25% were considered low, 50% moderate and 75% high. The potential for publication bias was assessed visually using funnel plots and Egger's test for funnel plot asymmetry. To consider between-trial variance, a method of moments, random effects meta-analysis was utilized. Since the use of random effect models may overestimate treatment effects, fixed effect models (which produce more conservative estimates) were also conducted and compared as a sensitivity analysis.

Pre-planned subgroup meta-analyses (intervention components, behavioural approach, intervention setting, and risk of bias summary score) and a series of meta-regressions (intervention duration, sample size, and mean participant age) were planned (if $I^2 \geq 50\%$) to test potential effect modifiers.

6.4 Results

Figure 6.1 shows the PRIMSA Flow Chart for the entire review process. Twenty-five trials met the inclusion criteria for this review. Reasons for exclusion at the full text phase (N=120) are outlined in A.6.6. Eight trials were excluded from the meta-analyses following data requests (N=25) due to: no response (N=5), data being unavailable (N=1), or data not provided in the required format (N=2) (See A.6.7). Characteristics of the final 17 trials included in the meta-analyses are summarized in Table 6.2 and included by trial in A.6.8.

The mean baseline sample size of included trials was 464 participants (median: 436; inter-quartile range (IQR): 178-700). The duration of interventions ranged from 1.5 to 24 months, with a median of 6 months (IQR: 5-12). The majority of the included trials were conducted in Europe (65%) followed by Australasia (23.5%), North America (5.9%) and South America (5.9%). Overall, 53% of trials presented a high risk of bias summary score, 18% low and 29% unclear.

Table 6.2 Characteristics of trials included in meta-analysis of school-based physical activity interventions (n=17)

		No (%)
Country of implementation	Australia	4 (23.5%)
	Northern Europe	5 (29.5)
	Western Europe	5 (29.4%)
	Central Europe	1 (5.9%)
	North America	1 (5.9%)
	South America	1 (5.9%)
Level of randomization	School	13 (76.0%)
	Classroom	4 (24.0%)
Intervention components *	Educational	14 (82.3%)
	Social environment	17 (100.0%)
	Physical environment	3 (17.6%)
Intervention setting	School plus afterschool/community components	13 (76.5%)
	School only	4 (23.5%)
Behavioural approach	Targeting PA only	10 (58.8%)
	Targeting PA alongside other health behaviours	7 (41.2%)
Mean baseline sample size	464 (median: 436; interquartile range (IQR): 178-700)	
Mean number of schools per trial	20 (median: 14; IQR: 12-18)	
Mean intervention duration	9 months (median: 6; IQR: 5-12)	
Mean age	10·6 years (median: 11·2; IQR: 9·5-12·0)	

* Categories are not mutually exclusive

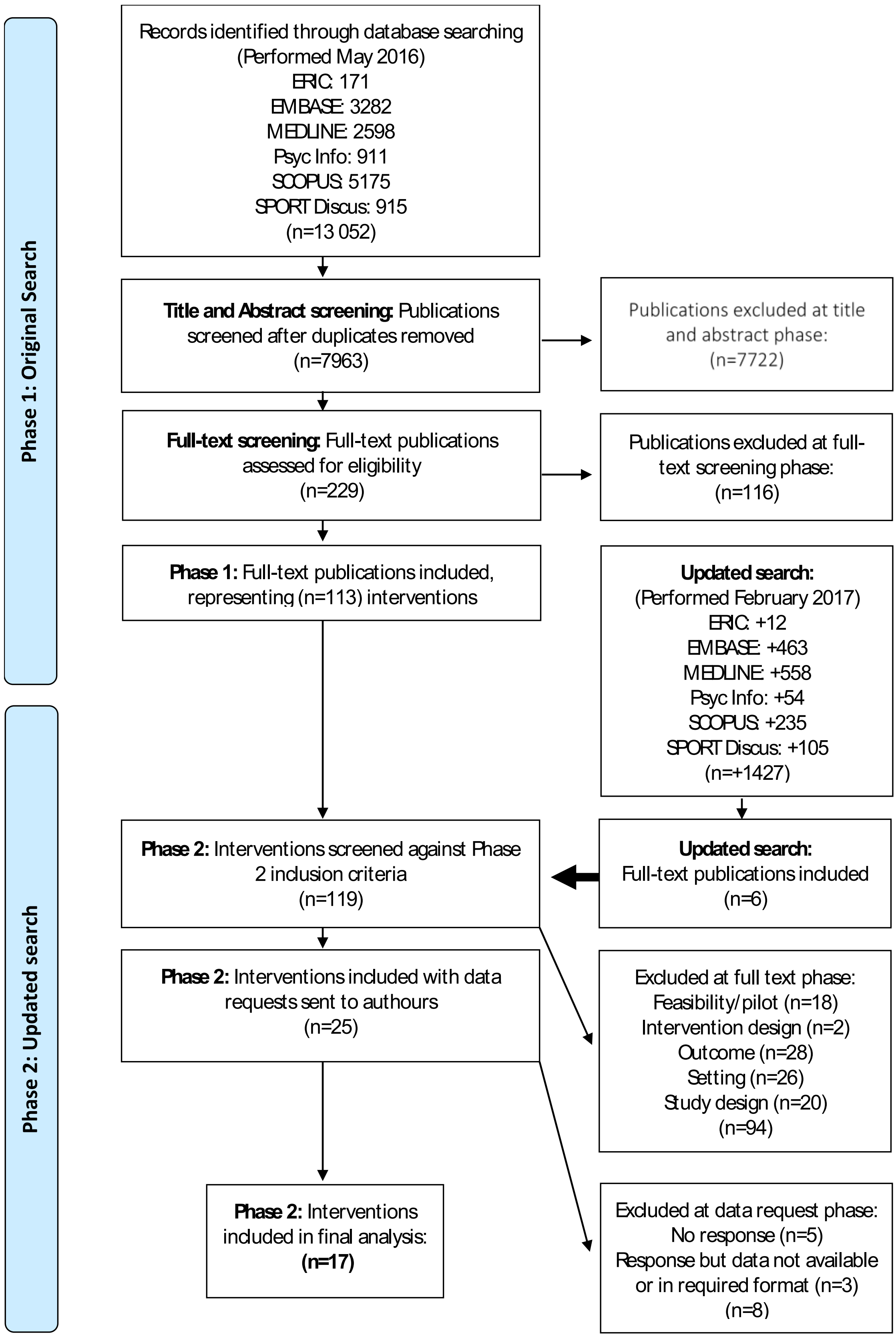


Figure 6.1 Flow chart of study selection, including both Phase 1 & 2

6.4.1 Main intervention, gender and SEP intervention effects

The main effect meta-analysis showed a non-existent (SMD: 0.02) and non-significant (95% CI: -0.07 – 0.11) pooled effect of the interventions on daily minutes of MVPA (Figure 6.2).

Figure 6.3 and 6.4 outline the intervention effects by gender. The girls' meta-analysis indicated a trivial (SMD: 0.07), but non-significant effect (95% CI: -0.07 – 0.21). Similar findings were found for boys (SMD: 0.05; 95% CI: -0.09 – 0.19). There was also no evidence of a statistically significant difference in intervention effect between girls and boys (p-value: 0.97).

Similarly, there was no evidence of differential intervention effect by SEP. Figure 6.5-6.7 outlines the effect on children from low SEP (SMD: -0.01, 95% CI: -0.12 – 0.11), medium SEP (SMD: -0.06, 95% CI: -0.17 – 0.05) and high SEP (SMD: -0.01, 95% CI: -0.13-0.11) households. There was no evidence of a statistical difference in intervention effectiveness by SEP (p-value: 0.68).

Figure 6.2 Main effect: Forest plot of standardized mean difference of change in physical activity between intervention and control groups of school-based physical activity interventions

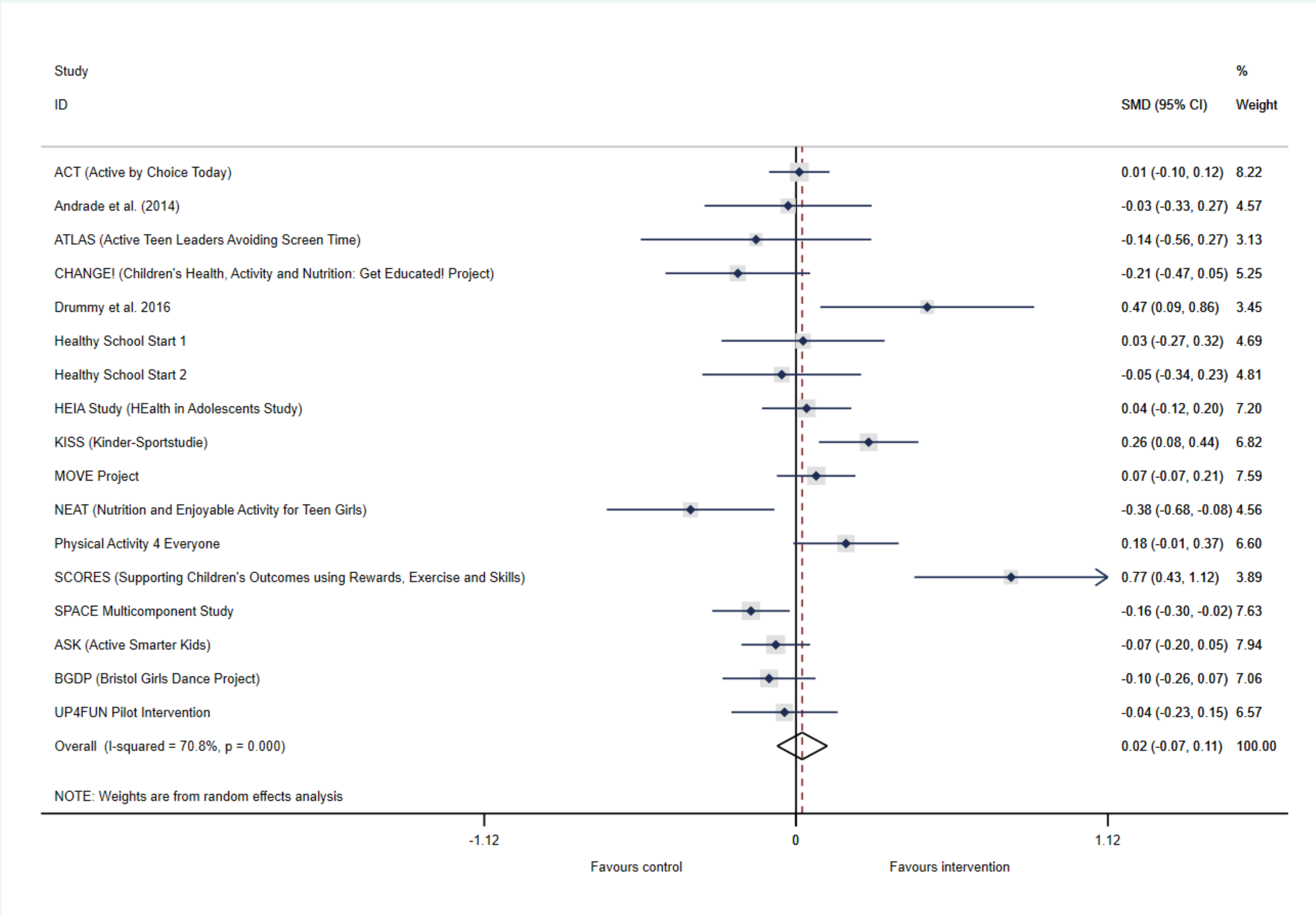


Figure 6.3 Girls: Forest plots of standardized mean difference of change in physical activity for girls between intervention and control groups of school-based physical activity interventions, for girls

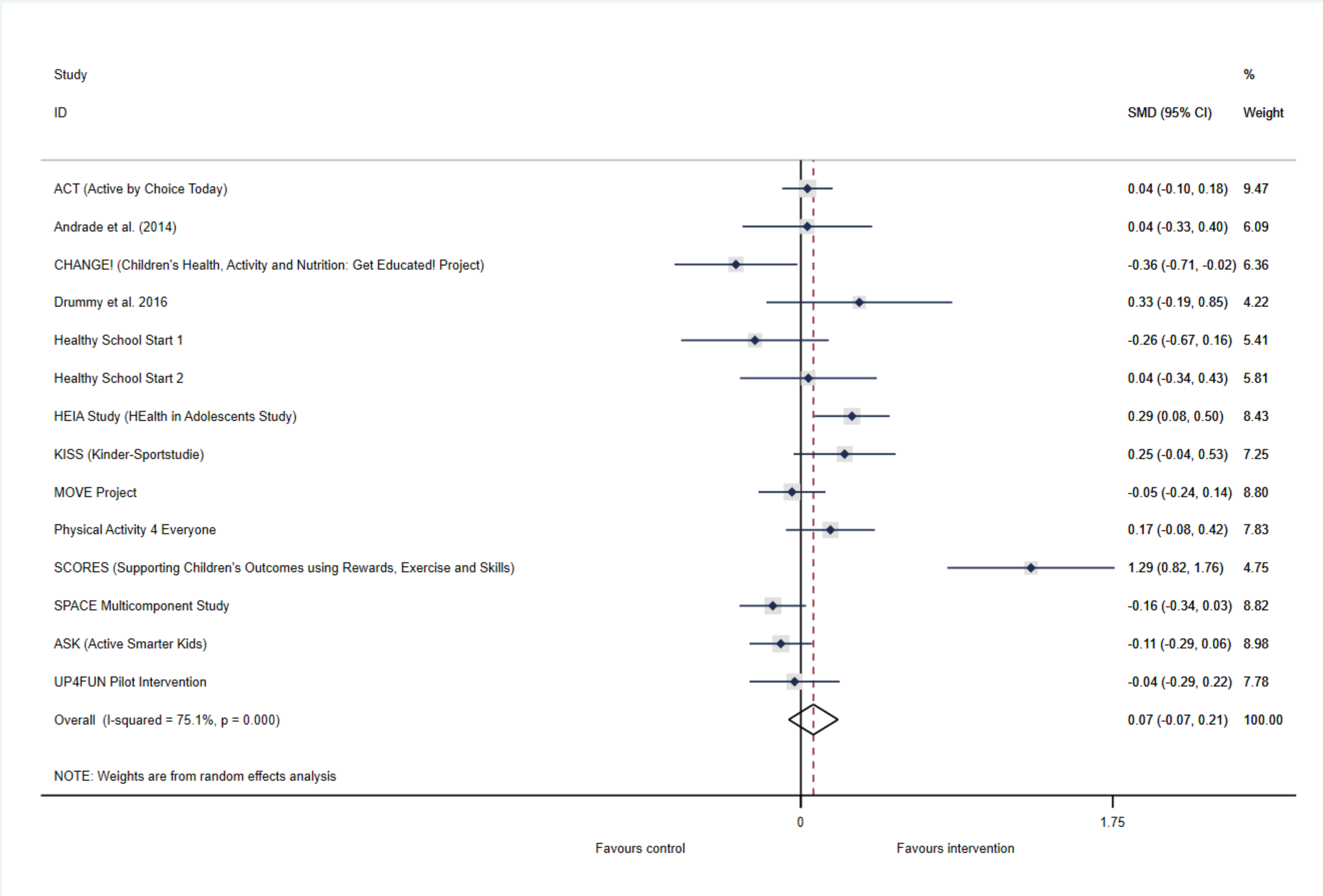


Figure 6.4 Boys: Forest plots of standardized mean difference of change in physical activity for boys between intervention and control groups of school-based physical activity interventions, for boys

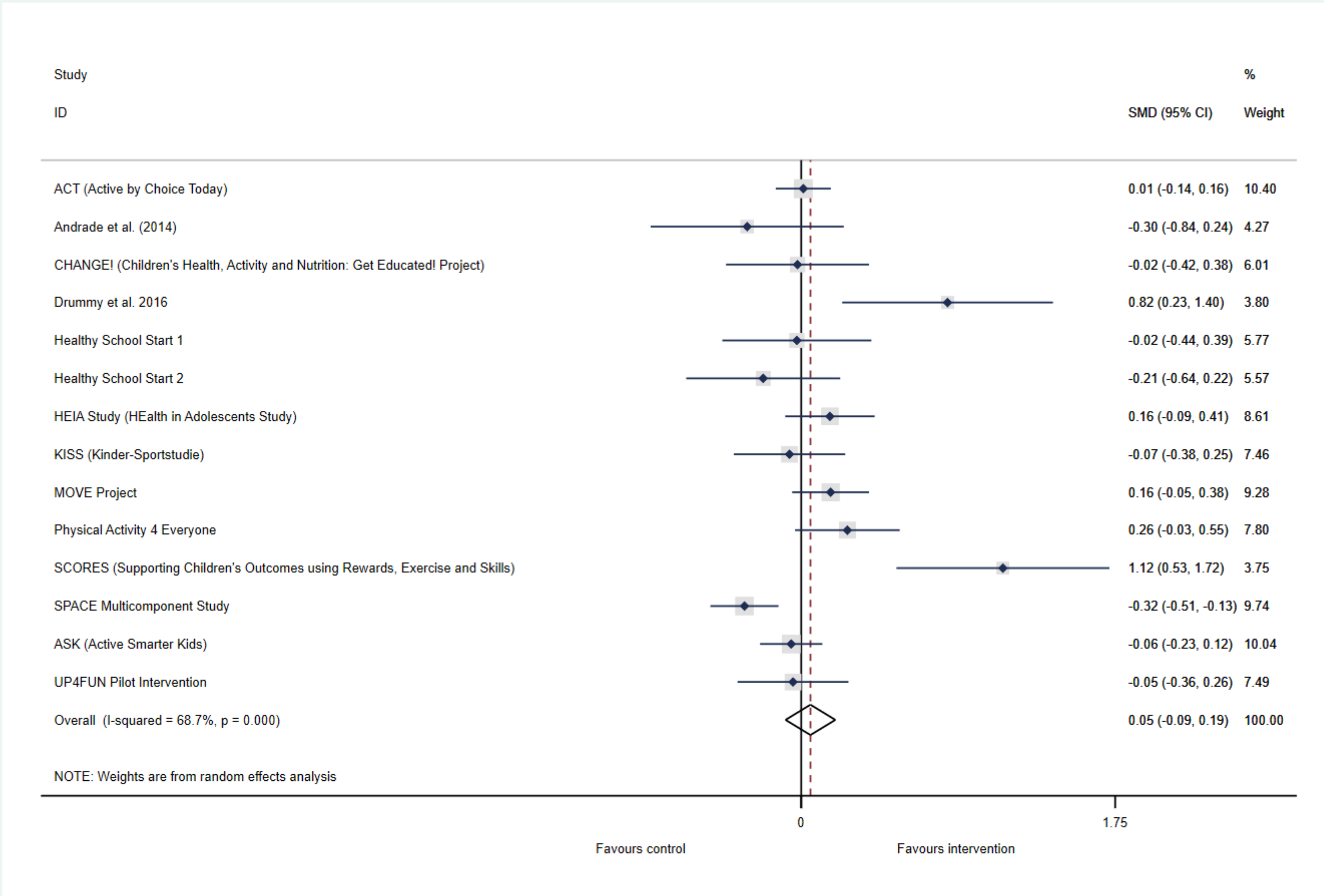


Figure 6.5 Low SEP: Forest plot of standardized mean difference of change in physical activity between intervention and control groups of school-based physical activity interventions, for low SEP children

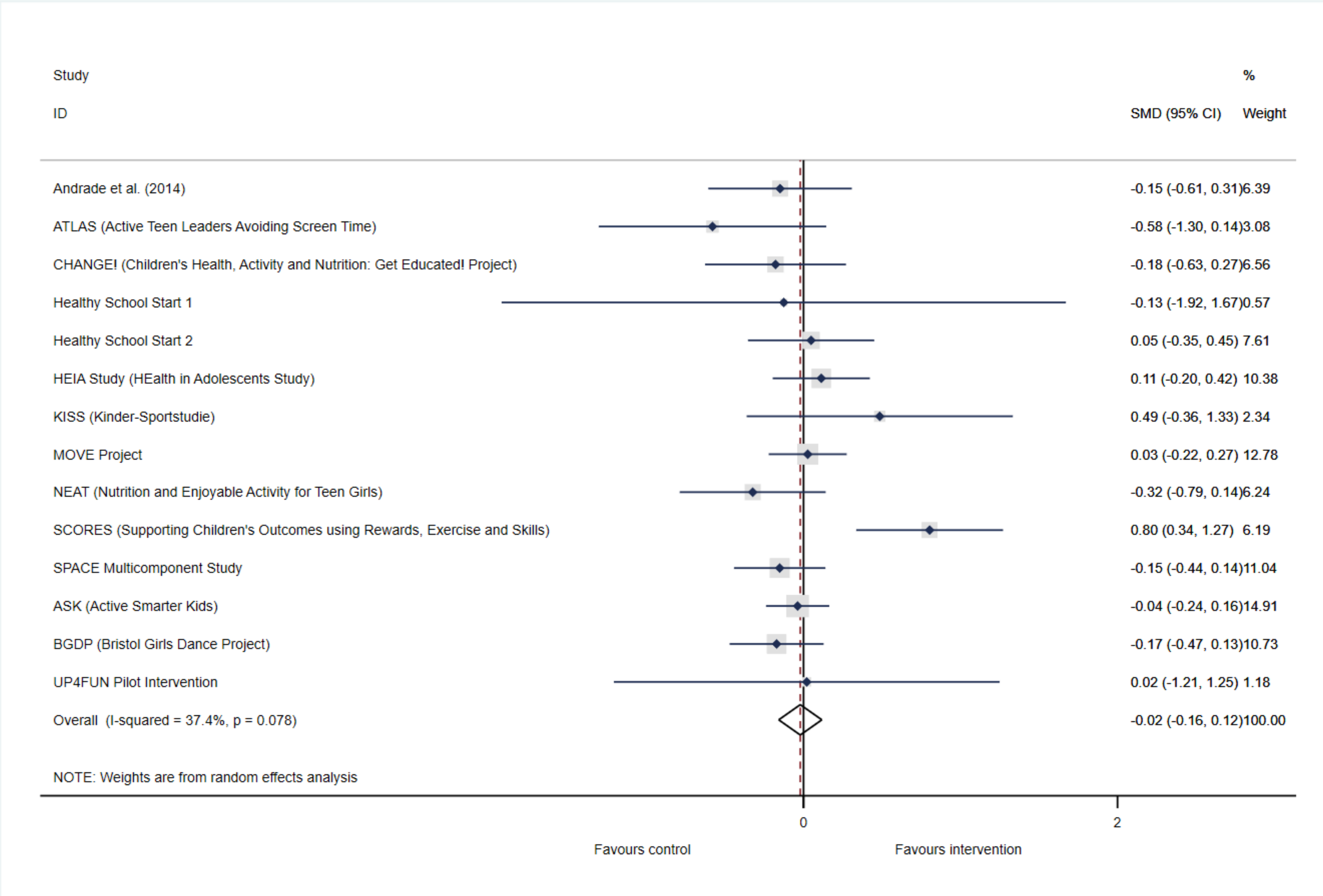


Figure 6.6 Middle SEP: Forest plot of standardized mean difference of change in physical activity between intervention and control groups of school-based physical activity interventions, for middle SEP children

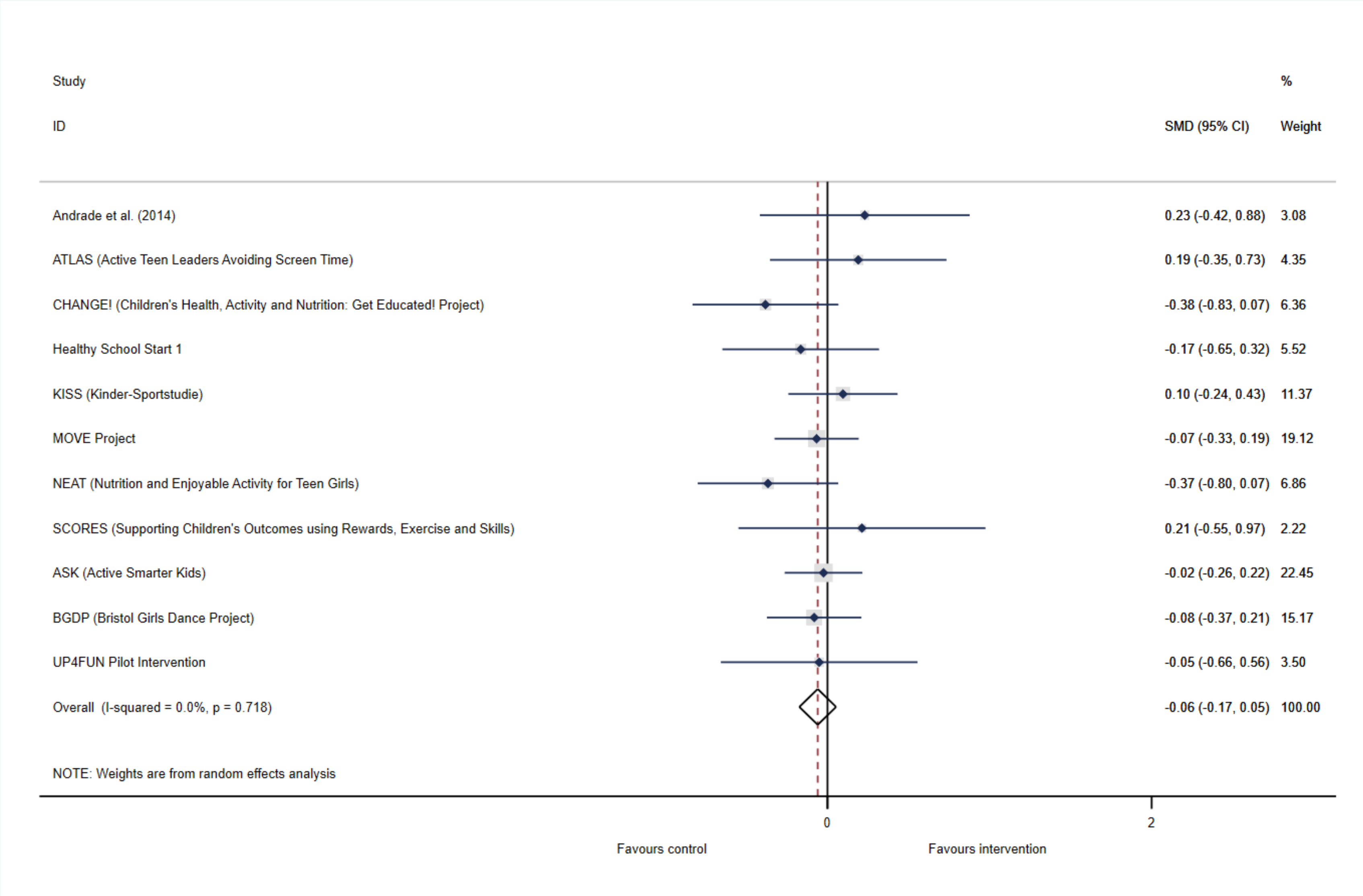
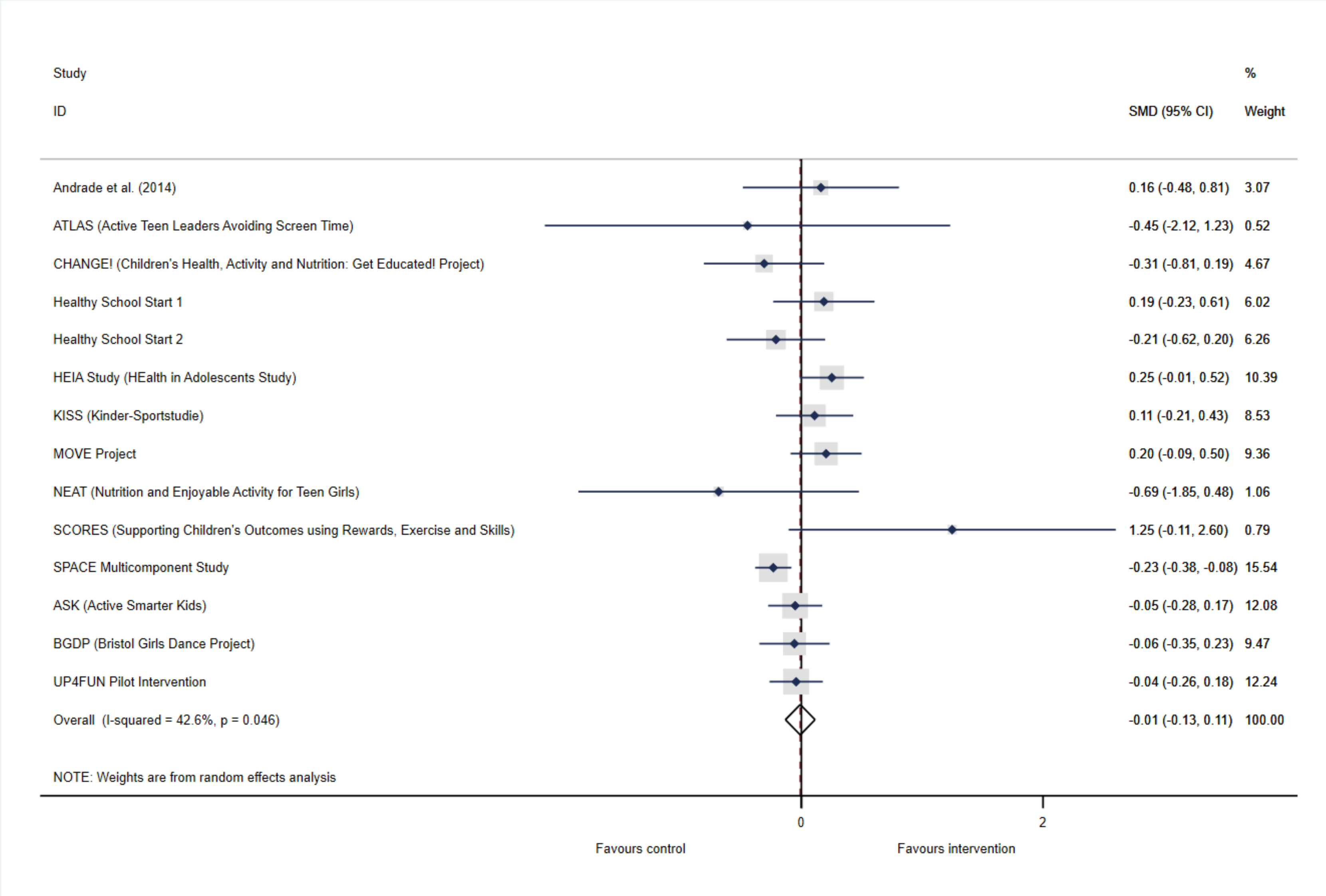


Figure 6.7 High SEP: Forest plot of standardized mean difference of change in physical activity by high SEP, between intervention and control groups of school-based physical activity interventions, for high SEP children



6.4.2 Publication bias

Eggers test for asymmetry of the funnel plot, was not significant (Coef: -0.08, p-value: 0.49), indicating no evidence of publication bias (See A.6.9).

6.4.3 Exploration of heterogeneity: Meta-regressions and sub-group analyses

Given the presence of high levels of heterogeneity (I^2=70.8%) the pre-planned meta-regressions and subgroup analyses were conducted. Meta-regressions revealed no evidence of heterogeneity by sample size (p-value: 0.57), intervention duration (p-value: 0.98) or age (p-value: 0.12) (See A.6.9). There was a non-significant trend towards a decrease in SMD with increasing mean participant age.

Subgroup meta-analyses by intervention characteristics of interest (behavioural approach, intervention setting and risk of bias summary score) revealed no significant differences in effect estimates (See A.6.9). There was insufficient heterogeneity in intervention components (social environment, physical environment, educational components) to enable subgroup analyses.

6.5 Discussion

This systematic review and meta-analyses provide the strongest collated evidence to date on the effectiveness of school-based physical activity interventions. I found that when restricted to cluster-randomised controlled evidence utilizing accelerometer-measured outcomes, school-based interventions in children and adolescents are not effective in increasing minutes spent in MVPA across the full day, and that this finding did not differ by gender or SEP.

To my knowledge this is the first meta-analysis in young people's physical activity promotion to pool accelerometer data with comparable outcome metrics. To rigorously answer my research questions, I collated mean daily minutes of MVPA measured by accelerometery. This decision was made in consideration of: a need for objective measurements that are equally valid across population subgroups,[47] the importance of full day activity change for health benefit,[305] and evidence of differential health benefits related to different physical activity intensities.[307] While accelerometers provide valid and reliable estimates of activity, they have inherent limitations including an inability to classify behaviour, detect certain activities (e.g. cycling and swimming), upper body movements or changes in terrain.[308] Successful author re-analysis requests enabled, for the first time, the pooling of intervention accelerometer data with comparable outcome metrics. Moreover, standardized and complete outcome data (N, mean, SD), permitted the utilization of mean change effect estimates, an approach that strengthens the robustness of the findings by accounting for group baseline differences.[309] However, the analyses included only a subset of relevant available data (n=8 were excluded due to inadequate or unavailable data). Calculation of Rosenthal's failsafe number, representing the number of studies that would be required to refute the main effect meta-analytic conclusion, indicates low potential for biased conclusions.[310] I estimate that at least 20 further trials, all with significant and positive intervention effects, would be needed to alter the main findings (See A.6.10). Moreover, no evidence of publication bias was observed, even in the sub-set of studies included in the analyses. Lastly, while it is concerning that 53% of included trials had an overall high risk of bias score, a subgroup meta-analysis by risk of bias was not significant. High risk of bias scores were primarily driven by attrition and lack of clarity regarding how missing data was handled within the analyses (A.6.11).

The major strengths of this review compared to previous work are the pooling of comparable accelerometer-based outcome measures of full-day MVPA and the assessment of equity effects. In contrast, previous reviews used either self-reported outcomes,[110,112] or pooled effects of incomparable outcomes derived from objective tools.[115,118] I restricted inclusion to objective measurements given evidence of poor validity and reliability of self-report and observational methods.[47] Additionally, given the growing evidence of the differences in activity intensities and patterning between subgroups of children,[311] I restricted inclusion to trials for which accelerometer assessed minutes of MVPA across the full day could be obtained. The scoping review (presented in chapter 5)[302] identified that asking authors to conduct re-analysis was the only way to obtain relevant data on equity effects by gender and SEP. Thus, in addition to providing a pool of comparable data, these author requests allowed me to exploit the potential of data that had been collected, but not previously reported on. Restricting inclusion to a homogeneous group of school-based trials limits the generalizability of the findings to school-based efforts to promote physical activity. However, this represents the majority of the available evidence and maximized the reliability and robustness of the conclusions made.

Whilst a lack of an overall effect could mask opposing effects in different population subgroups, I found no evidence of an effect in any gender or SEP subgroups. This suggests either that the intervention components are not effective or that they are not reaching target populations, rather than they are effective in some groups but not others. Substantial effort is commonly devoted to intervention theory and development, as demonstrated by the included KISS and CHANGE! trials.[312,313] I suggest that similar attention is now required to understand the intervention implementation process of these complex interventions and how this can be optimized in different contexts. The complex and multicomponent nature of most school-based physical activity interventions may make them particularly vulnerable to poor implementation fidelity.[314] Prior evaluations have demonstrated considerable differences in intervention intensities between classes and schools.[315] Process evaluations are critical to understand the implementation success and the contextual factors that influence how an intervention works. However, based on the pool of studies included in this review, process evaluations are rare: only 18% (n=3) of included trials conducted a process evaluation. Two of these process evaluations assessed the issue of intervention fidelity, both concluding wide variance in implementation of the program across schools and settings. Beyond determining if the intervention 'worked', outcome evaluations do little to inform future theory development, or context-specific policy and practice. Robust evaluations of interventions known to be delivered with maximum possible implementation fidelity are required to confirm that school-based interventions are not effective in changing physical activity. Investigators need to make substantial efforts to maximize, measure, and understand the impact of implementation fidelity across the intervention process.

Despite the promise of schools as a universal context to influence health behaviours, my review and other emerging trial evidence,[316] suggest current efforts are not having an impact. It is unlikely that we will make substantial changes to population levels of, and inequities in, physical inactivity and obesity in children by focusing our collective efforts on only one setting, such as schools, when the wider environments are insufficiently supportive for behaviour change.[317,318] This is exemplified by some trials reporting positive effects during school hours, which are attenuated when assessing activity across the whole day as analysed here.[304] Multi-dimensional intervention strategies across settings are likely required to achieve sustained effects across the whole day. The contribution of different components within such strategies needs to be carefully considered and assessed to maximize cost-effectiveness. Further research to understand dilution of intervention effectiveness across a child's day would be valuable.

This review focused on a subset of the literature on physical activity promotion in young people: school-based interventions. I also restricted the assessment of equity effects to gender and SEP. This is because the scoping review (presented in chapter 5) revealed limited RCTs in non-school settings, using objective physical activity measures across the full day, and limited data on equity characteristics beyond gender and SEP.[302] There is, thus, a need for further primary research in different intervention contexts using high-quality outcome measures, and reporting outcomes both overall and across a range of different equity subgroups. Given theoretical and empirical evidence that interventions can be differentially effective across population subgroups,[173] it is critical that relevant equity characteristics are assessed. While it may not be possible to power all studies to address equity questions, consistently collecting this data will enable future meta-analyses like ours. It may also be timely to consider the standardization of outcome reporting in physical activity trials. In 35% of trials included in this review, published conclusions of positive effects were not confirmed in my re-analyses using the a-priori established outcome measure of accelerometer-derived minutes of MVPA across the whole day.[300,319–323] All interventions included in this review were hypothesised to change activity across the whole day and whilst individual trials may have had different primary outcomes for good reason, it is important not to lose sight of the overarching aim of physical activity promotion – to improve health outcomes. This requires a focus on full day behaviour, and an increased understanding of effectiveness across times and settings.[324] Encouraged by the success of responses within this review, authors at the minimum, should be accommodating to re-analysis requests. Working towards more broadly available data would further facilitate the efficient and transparent synthesis of evidence.

6.6 Conclusion

This systematic review and meta-analysis demonstrate that school-based physical activity interventions have not been effective at increasing children's accelerometer-measured daily time spent in MVPA. This null effect is equitable across gender and SEP. These null results may be due to well-designed interventions not reaching target populations as intended, or effects not maintained across the day. Further assessment and maximization of implementation fidelity is required before it can be concluded that school-based activity promotion interventions have no contribution to make to reducing physical inactivity and obesity in children.

6.7 Contributions

I designed this study in collaboration with Esther van Sluijs and Jean Adams. I conducted the literature searches in each of the identified databases. I conducted the title, abstract and full text screening in duplicate with Esther van Sluijs, and the data extraction and risk of bias assessments in duplicate with Jean Adams. I ran all of the statistical analyses, critically interpreted the findings and drafted the full manuscript. Esther van Sluijs and Jean Adams contributed to the interpretation of the results and drafted manuscript. I would additionally like to thank all of the intervention authors for their willingness, time and efforts to contribute to this analysis through the provision of data.

7 OVERALL DISCUSSION

7.1 Introduction

The overall aims of this thesis were to investigate the socioeconomic patterning of children's physical activity behaviour and to explore whether existing activity promotion efforts are generating differential effects. These aims were addressed in five chapters encompassing a review and series of secondary data analyses. Each chapter includes an interpretation of the results, a contextualisation within the existing literature, a section outlining the strength and limitations of the study and recommendations for future research.

Across the observational analyses (Chapters 2-4) the discussions include reasons for the observed intensity differences between socioeconomic groups, the strength of evidence regarding the implications of the differences observed and an analysis of the benefits of high intensity activity, including the focus and variability of national physical activity guidelines, amongst others. The subsequent intervention analyses (Chapters 5-6) discuss a range of factors including statistical considerations when investigating and encouraging differential effect analyses, challenges with the measurement of equity characteristics, the vulnerability of multi-component interventions to poor implementation fidelity and the role of process evaluations in understanding implementation. These chapter-specific discussions are not repeated here in the overall discussion which instead focuses on overarching points.

This chapter summarises the main findings across the epidemiological studies (Chapters 2-4) and the intervention analyses (Chapters 5-6), discusses general methodological strengths and weaknesses of the overall approach, and finally gives an overview of implications for public health and recommendations for research.

7.2 Summary of findings

The research presented in this dissertation reveals socioeconomic differences in the intensity patterning of children's physical activity behavior. The analyses presented are the first to establish that differences in the relative participation of VPA and MPA between socioeconomic subgroups mirror inequalities in childhood obesity across populations. By demonstrating that the commonly applied aggregate measure of MVPA can overlook socioeconomic inequalities in the most important segment of physical activity for health outcomes, my research advances current knowledge and provides insights regarding the so-far inconclusive state of the evidence base.[166]

The results of the intervention analyses make a significant contribution to the field by providing the strongest collated evidence to date regarding the effectiveness and equity of school-based physical activity interventions. By employing author re-analysis requests, which enabled the pooling of accelerometer-assessed physical activity data with comparable outcome metrics, I demonstrate that interventions have not been effective at increasing children's daily MVPA. Centrally the unique equity approach in my analysis adds value through demonstrating that the null effects are consistent across socioeconomic groups and gender. Together these findings suggest that in some cases interventions may not be reaching target populations as intended and that in other cases effects may not maintained across the full day.

The result that children with increased SEP attain proportionally higher intensity physical activity, irrespective of the national context, are strengthened by the replication of supporting findings across three observational datasets spanning South Africa, the UK and sixteen European countries. The finding from the BT20+, that less affluent South African adolescents spend less time in organized sport and physical education but more time walking for transport and engaged in informal activities – should be generalized with caution. The comparatively small sample, the use of self-report data and the time-lag since the data collection need to be considered when interpreting the results. While my findings reveal, for the first time, socioeconomic differences in the distribution of physical activity behaviour, they need to be further investigated. Research attention is needed particularly with regards to females given the more pronounced socioeconomic inequalities in physical activity observed in this subgroup which parallel rising regional adiposity rates disproportionally concentrated in females.

The strength of the trends I found can be seen in the replication of the associations observed in a UK and a European dataset covering 16 countries, both with accelerometer-assessed physical activity. Accelerometer measurement allows adjustments for MPA to be made when analysing

VPA which is important as it accounts for differences in the accumulation of overall activity between children. The European dataset I developed is the largest and most diverse to date, of both harmonised accelerometer and SEP data in children. My multi-country analysis reveals that alongside spending more time engaged in VPA, more socioeconomically affluent children have lower overall levels of MVPA, which is paralleled by lower levels of overweight and obesity. While the size and breadth of participants included provide a robust case for the European context, this relationship needs to be investigated in other settings and populations. The observed associations were relatively small, however, and while I suggest in light of the evidence that the differences are in fact impactful on a population level, the overall impact of these differences need to be further investigated. This could be assessed through the pooling of data from children's accelerometer studies and examination of associations of VPA with cardiometabolic risk factors.

The scoping review (Chapter 6) I conducted revealed a surprising scarcity of consideration for equity across children's physical activity promotion efforts. Despite the fact that most trials collected equity characteristics at baseline, few controlled trials report the analyses of differences in intervention effect across the outlined equity characteristics. There is accordingly a lack of understanding of subgroups that may particularly benefit from, or be disadvantaged by, current intervention efforts. Due to the nature of this research as a scoping exercise, I was only able to provide a overview and was unable to draw conclusions regarding the extent of differential effectiveness across the literature. Additionally, the findings are limited in their ability to investigate interaction and subgroup analyses in a detailed manner, due to the heterogeneous set of intervention studies combined.

The strength of the intervention analyses I presented are in the subsequent in-depth intervention meta-analysis I conducted using relevant unpublished data of cluster-randomized school-based trials attained through data requests to the original authors. Using re-analysed accelerometer data, I demonstrated that current multicomponent school-based interventions are not effective in increasing minutes spent in MVPA across the full day; and that this ineffectiveness does not differ by SEP or gender. This finding which provides the strongest evidence to date that current school-based efforts do not positively impact young people's physical activity across the full day, is strengthened through its pooling of intervention effects with comparable outcome metrics and standardised processing of intervention effects through mean change effect estimates, which enables adjustments for group baseline differences. The analysis of both overall and subgroup equity effects points to a need to assess intervention implementation processes. However, these findings are limited to school settings and ignore a range of other, potentially relevant, equity factors.

The remainder of this discussion section examines methodological issues across the thesis in more depth: I also discuss the implications from a policy point of view and provide recommendations for future research.

7.3 Methodological considerations

Methodological considerations that are specific to the respective analysis are outlined within each chapter. This section instead provides an overview of methodological considerations which cut across the entire thesis. They are clustered by their effect on internal and external validity. Internal validity refers to the extent to which conclusions drawn from the experimental data are free from confounding issues. Influences on the internal validity of this thesis are considered across study design, confounding, chance, exposures and outcomes. External validity refers to the extent to which findings can be applied to other populations or settings. Effects on external validity are addressed through the consideration of selection and attrition bias, and generalisability.

7.3.1 Internal validity

7.3.1.1 Study design, confounding and chance

7.3.1.1.1 Study design

The analyses of the Birth to Twenty (Bt20+), Millennium Cohort Study (MCS) and DEDIPAC European database each are cross-sectional in design. While cross-sectional analyses are valuable in their ability to establish an association between sociodemographic factors and physical activity at one point in time, they are not able to explore causality or potential mediators.

As I cannot draw conclusions regarding the direction of established associations, reverse causality cannot be completely ruled out. While causal judgements cannot be made, health inequalities research suggests that the effect of reverse causation from health behaviours to SEP is small.[325] The conducted analyses centrally investigate the impact of SEP on various dimensions of physical activity behaviour. In the context of these analyses, reverse causation, refers to a set of pathways whereby children with lower levels of physical activity have a reduction in SEP as a result. It is highly unlikely that a child's physical activity behaviour influences their parent's SEP. This assumption is supported by an array of evidence supporting social causation of health behaviour.[326]

Longitudinal studies can better support the establishment of casual inference through temporality (the risk factor preceding the outcome) and specificity (linking changes in a risk factor with changes in an outcome).[327] While both MCS and BT20+ are longitudinal cohorts, the analyses in this PhD are cross-sectional due to data availability. In MCS (Chapter 2), accelerometer data is currently limited to one follow-up point which is why it was treated as a cross-sectional analysis; it was however valuable to use given the large, diverse, and nationally representative sample of objectively measured physical activity. The BT20+ (Chapter 3) as the largest population cohorts of children in Africa provides a unique opportunity to assess the relationship of SEP to physical activity in a low-resource context. While physical data was collected annually from years 12 through to 17 in the BT20+, SEP data was only collected at years to 13 and 16, which restricted the analyses conducted to these two follow-up points.

The DEDIPAC analysis conducted (Chapter 4) encompasses the International Children's Accelerometer Database (ICAD), which contains a substantial amount of longitudinal accelerometer data. I justified the use of the cross-sectional DEDIPAC database given the substantial increase in diversity and breadth of countries across the European context. Restriction to longitudinal data would have restricted the analysis to 8 cohorts (22% of the cohorts included in the analyses presented). Being able to answer the central research question of if the relationship between SEP and physical activity differs between national contexts required a database with significant levels of heterogeneity. It would be worthwhile for future research to replicate the analysis in the longitudinal sub-group.

The final two chapters were designed as a two-staged systematic review of intervention studies. The extent to which a full systematic review can unbiasedly draw conclusions about the effect of an intervention is influenced by the validity of the pooled data and the effects included. To ensure the inclusion of a homogeneous set of trials, stringent inclusion criterion were set (These included: accelerometer-assessed physical activity across the full day at baseline and follow up, at least four weeks in intervention duration and cluster randomised controlled trials). Randomised controlled trials are commonly considered the gold standard within public health research to avoid threats to internal validity established by other study designs because the process of randomisation eliminates systematic selection biases and enables differences in outcomes to be tested and attributed to true differences in expsoures.[328]

To further assess potential threats to the internal validity of the systematic review, each study that met the inclusion criteria was also assessed across five domains of bias (selection, performance, attrition, detection and reporting) and classified as presenting a low, high or unclear risk of bias. These bias ratings were tested and demonstrated to not affect the overall effectiveness through a subgroup meta-analysis.

The validity of the systematic review is strengthened by the meta-analytical approaches employed. The data re-analysis requests provided standardised and complete outcome data of the mean daily minutes of accelerometer-assessed MVPA at both baseline and follow-up. This enabled the calculation and pooling of mean change effect estimates, an approach that strengthens the robustness of the findings by accounting for group baseline differences.[309]

7.3.1.1.2 Confounding

The existence of uncontrolled explanatory variables poses a threat to the internal validity within any given analysis. Confounding factors are those that are associated with both the outcome and exposures but not the causal pathway. If uncontrolled for, confounding factors can both mask an actual association or falsely demonstrate an association, leading to flawed conclusions.[329] Across all analyses, each of the statistical models applied has been adjusted for identified confounding variables. In addition, multivariate models were used throughout the analyses which enabled the adjustment and control of multiple variables simultaneously through mathematical modelling.

As with any secondary data analysis, the considered adjustments were restricted to variables collected within the process of data collection. There were analyses in which additional adjustments could have been included if the data was available. For instance, within the DEDIPAC analysis in which BMI z-score is the outcome and SEP the exposure, it would have been appropriate to adjust for diet, however this data was not available. Furthermore, across all analyses it is likely that residual confounding remains, possibly by factors that are unknown and cannot be measured.[330]

Across the two analyses with objective accelerometer data (MCS and BT20+), I adjusted for MPA when assessing VPA as an outcome. The central question I was interested in was with regards to proportionality and understanding the distribution of MPA versus VPA, irrespective of a child's overall level of activity. As illustrated, it is possible that children have the same overall level of activity, but significantly different proportions of VPA within this. Adjusting for MPA when analysing VPA accounts for differences in the accumulation and distribution of overall activity across children. I was not able to make an analogous adjustment in the analysis I conducted in BT20+ due the nature of the self-report data. The four physical activity domains are assessed independently and thus answer related, but independent, questions.

While confounding can be adjusted for after data collection using statistical models, it is better to control for it through randomisation in the study design phase.[329] Through the successful random assignment of participants, RCTs minimise the possibility for confounding through the generation of groups that can be deemed comparable with respect to both known and unknown confounding factors. However, trials are only feasible for certain research questions. Ethically it would not be possible to randomise children by SEP to intervention conditions with differing physical activity intensities and health benefits.

As discussed, the intervention meta-analysis is restricted to cluster-randomised controlled trials (C-RCTs), in which groups (in this case, schools or classrooms) are randomised. These strict study design inclusion criteria reduce the potential for bias within included interventions in comparison to other evaluative approaches. While cluster-RCTs are the go to 'gold standard' method of allocation and evaluation within school-based contexts, they are still susceptible to various methodological challenges, including the potential for confounding if clusters differ substantially.[331] Design strategies such as matching and stratification can be employed to ensure balance between groups. However, as a meta-analysis of outcome data, this is a dimension I was unable to control for. It is thus possible that the internal validity of the findings was affected through imbalanced intervention and control arms with regards to potential confounding factors.

7.3.1.1.3 Chance

Across all statistical analyses presented in this dissertation, I tested for null significance levels of 0.05. This p-value represents the probability of obtaining the observed effect estimate if the null hypothesis was true. Comparing p-values to an arbitrary level (typically α=0.05) is the most commonly used statistical method of establishing significance across the medical sciences.[332] The use of p-values as a binary threshold of significance is widely criticised.[329] In line with recent calls to action, the interpretations I present in this thesis attempt to also discuss the point estimates, confidence intervals and the uncertainty within them.

The rigour of the statistical analyses presented are strengthened by the large sample sizes which lower the likelihood of chance findings.[333] The large sample sizes lead to less uncertainty and small confidence intervals, establishing associations with high precision. While relatively small in size, I suggest that the significant associations established in the large MCS and DEDIPAC datasets are relevant at a population level and have public health significance.

7.3.1.2 Error and bias in measurement

7.3.1.2.1 Exposures

To correctly assess associations between sociodemographic factors and behaviour both the exposure and the outcome need to be accurately quantified. The analyses presented in this thesis use multiple exposures including SEP, gender, and self-identified ethnicity. Both ethnicity and gender are relatively straight forward to accurately capture through either questionnaires or interviews. SEP is comparatively more difficult to assess given the complexity of the concept, the range of indicators used and pathways captured. Across the analyses presented, a multitude of SEP indicators were used including equivalised household income, paternal and maternal education and household physical assets. Each SEP indicator has its own limitations which are individually considered within the chapters and summarised in Table 1.5.

Given that each SEP indicator may operate through its own causal pathway or mechanism, understanding the individual casual effects on behaviour can be challenging.[334] It is suggested that choosing the most appropriate variables for measurement of SEP should be dependent on the consideration of causal pathways and the relevance of the indicator for the populations and outcomes under studied.[335] In each analysis, the proposed mechanisms and pathways of how the available SEP indicators influence health within the context was considered (e.g. the use of household physical assets within the South African context in BT20+). The selection of the SEP indicators was made recognising that a single measure of SEP may show an association with physical activity and adiposity but does not encompass the entirety of the effect of SEP on health behaviour. Accordingly, where feasible, I used multiple indicators to be able to compare differences in size and effect (e.g. the use of both equivalised household income and maternal education in MCS).

From a socioecological perspective, determinants of health operate simultaneously both at the level of the individual and at the level of social contexts.[336] This thesis is limited in its consideration of the contextual aspects of social determinants, such as the characteristics of neighbourhood environments that effect physical activity behaviour and health outcomes.[337] Distinct domains of the neighbourhood environment (e.g. access to parks) have been demonstrated to be independently related to children's physical activity and health outcomes.[142] These broader level factors are not accounted for within the analyses and likely intersect with the individual SEP associations' observed.

7.3.1.2.2 Outcomes

A considerable strength of this thesis is the central use of accelerometer-assessed physical activity across four of the five analyses. The use of objective accelerometer data offers substantial value through its precise and accurate measurement of children's physical activity which reduces measurement error and removes responder, recall and interviewer bias.[50–52] Objective measurement of free living physical activity is particularly valuable when investigating differences between subgroups of children, as self-reported data has been shown to be differentially biased between subgroups.[56] My decision to restrict the majority of analyses to accelerometer data however has implications for the generalisability of the findings. Due to the high costs of monitors their use is restricted to research studies and contexts which can afford to employ them. The restriction to studies with accelerometer measurement across the full day in the entire sample, particularly in the intervention systematic review, resulted in pool of seventeen studies all from high-income country contexts, limiting generalisability. It is also possible that certain types of interventions are more likely to have accelerometer measurements across all participants then others.

The remaining analysis, the BT20+ cohort, subjectively assessed physical activity through an interview administered questionnaire. The use of subjective methods is subject to over-reporting due to social desirability and recall bias and as mentioned, potentially biased across subgroups of a population.[55] While the specific questionnaire used has been validated and thus extensively used across South African populations these inherent biases and limitations of subjective measurement remain. However, the subjective BT20+ physical activity data adds value through the provision of domain specific information on activity participation (organised sport, active travel, informal physical activity, physical education). While objective measurements would have provided precision and accuracy of measurement they would not have provided an understanding the specific contexts in which physical activity differs in this population.[56]

For the aggregated DEDIPAC analysis, the pooling of raw data, each using Actigraph accelerometers, enabled harmonisation using the same data processing and cut points. However, the accelerometer collection and processing decisions differed between studies, prior to the pooling and harmonisation. One central factor that needs to be considered is the variability in epoch lengths used (the interval of time over which the units of accelerometer measures are summed), which ranged from 5-60 seconds between studies. Substantial differences in intensity levels are observed through the application of different epoch lengths.[338,339] It is possible with the use of longer epoch lengths, short bursts of high intensity activity are combined with lower intensity activity leading to an under-estimation of MVPA and an overestimation of LPA.[340] The finer data resolution attained through shorter epoch lengths have been recommended in children and adolescent populations to effectively capture the characteristically intermittent activity patterns.[210,341] However this is a decision that is considered and made by the data teams of individual studies and thus varies.

Unlike DEDIPAC, the intervention meta-analysis is unharmonized. To simplify the data request to authors (to increase the likelihood of positive responses), it was left to each author's discretion what accelerometer cut-points and processing criteria were used. Given that minutes of MVPA has been demonstrated to differ based on the cut point used,[252] the quantification of

MVPA differed between included studies. However, given that each individual intervention was adjusted for baseline physical activity through the calculation of mean change scores, the effect estimates present the change individually, and thus are unlikely to be significantly affected by different approaches to data processing.

7.3.2 External validity

7.3.2.1 Selection and attrition bias

Selection and attrition bias across studies can detrimentally affect the wider generalisability of the study findings. Selection bias occurs in epidemiological studies when there is a systematic difference between the characteristics of samples selected for the study and the wider population.[342] Both of the cohorts I used, the MCS and BT20+, were representative of their respective populations at the point of enrolment. The MCS used a stratified sampling design which enabled appropriate representation of socioeconomically disadvantaged and ethnic minority children across the UK. All the analyses I conducted in MCS used survey commands to account for the stratified sampling design, alongside sampling weights to adjust for non-response between waves.

However, as with all longitudinal cohort studies the representativeness of both BT20+ and MCS studies was affected by participant attrition at subsequent waves of assessment and accordingly the representativeness of the samples. In MCS, the accelerometer sub-study required additional opting in from parents which affected participation rates. BT20+ was faced with substantial attrition; just over a third (32%) of the original cohort was included in my analytic sample. While this attrition is noted to be better then other longitudinal cohorts from LMICs, it is a substantial loss of participants. The 36 cohorts included in the DEDIPAC database are both longitudinal and cross-sectional in design, and are susceptible to issues of both selection and attrition bias. The exact extent to which each individual cohort is representative of their population, and thus the overall sample of the European countries included, is unclear and thus potentially susceptible to bias.

Similarly, the seventeen trials I pooled within my systematic review meta-analysis each employed different selection processes and contained varying levels of attrition. However, the risk of bias assessment I conducted deemed only three studies (17%) to have a high risk of bias with regards to selection and attrition bias. A subgroup meta-analysis of the overall assessed risk of bias score was not significant revealing that the effectiveness of studies was not influenced in a patterned manner by the risk of biases assessed.

Representativeness can lastly be altered in data processing if participants who do or don't provide valid data characteristically differ. The extent to which these biases affected the analyses I conducted is addressed within each chapter through drop-out analyses to compare the analytic versus excluded sample.

7.3.2.2 Generalisability

The central driver of external validity is the extent to which the findings can be considered generalisable. The epidemiological findings in this thesis are strengthened by the replicability of associations across three independent analyses. The inclusion of 36 cohorts across 16 countries, following the establishment of associations within a nationally representative UK cohort, provides a basis for generalisability across Europe and more widely to other high-income country contexts. The associations observed within the South African cohort should be treated with caution given the small sample size, data time-lag and subjective measurement methods. There is a need for further studies across, South Africa, sub-Saharan Africa and LMICs before the relationships established can be considered generalisable to populations within these settings.

Similarly, the trials included in the reviews were predominately from high-resource national contexts. Of the 113 trials included in the scoping review, 94% were from a European, North American or Australian context. The subsequent in-depth analysis of seventeen trials was similarly skewed to inclusion of these three dominant high resource regions and thus the findings of both are not generalisable beyond these contexts. There is a clear need for high quality intervention research from unrepresented regions, particularly low-resource country contexts.

Furthermore, the meta-analysis includes only multicomponent school-based interventions. The restriction to a relatively homogeneous set of school-based trials limits the generalisability of the findings to other settings. No restrictions, however, were imposed on intervention type or components which introduced heterogeneity. It is possible that the lack of effectiveness I observed is driven by pooling different types of interventions with opposing effects. Alongside process evaluations, future pooled analyses should work to establish which components of an intervention are effective and which are not.

7.4 Implications for public health and policy

The findings presented in this thesis have multiple implications for the field of public health and public health policy. Given rising prevalence rates globally, childhood obesity is increasingly a public health priority for governments,[343] with growing focus on promoting equity through reducing inequalities in health behaviours.[106] With national governments and international organisations prioritizing the equitable promotion of physical activity in children and adolescents,[40,86,344] the findings of this thesis have wide applicability.

The intensity differences in the patterning of children's physical activity behaviour by SEP suggest that more work should be done to promote VPA in children from lower SEP. While, additional research is needed to establish the significance of differences observed, my findings suggest these inequalities are persistent and widespread, and thus deserve attention moving forward. The parallel socioeconomic inequalities demonstrated between intensity distributions and adiposity (alongside strong evidence that has amassed over the past decade demonstrating the central role of VPA in adiposity reduction and health promotion) provide a new direction for investigations regarding the role of physical activity in widening inequalities in childhood obesity.

My findings reveal that the international focus of children's physical activity promotion centrally on MVPA should be evaluated and re-considered. The analyses I have conducted demonstrate that the repeated emphasis on MVPA may overlook significant differences in the relative contributions of MPA and VPA between population subgroups and tolerate significant inequalities in the most important segment of physical activity for health outcomes. Given the differences I observed a shift in focus away from complete dominance of the aggregate measure MVPA, to understanding differences in both VPA and MPA would be valuable.

Greater attention needs to be paid to equity characteristics in the implementation and evaluation of children's physical activity interventions. Current approaches have resulted in a lack of understanding of equity subgroups that may particularly benefit from or be disadvantaged by the wide range of existing intervention efforts. My call to action, which was disseminated through a publication in IJBNPA, appears to already be encouraging action across contexts, including as rationale for investigating effectiveness by gender in recently published evaluation of an adolescent high-school intervention targeting multiple health behaviors.[345]

The demonstration of the lack of effectiveness of school-based interventions is of direct policy relevance given the current widespread international and national focus of children's physical activity promotion across school contexts and systems.[40,111] Based on my findings I recommend that we continue to develop and evaluate school-based physical activity interventions within research contexts, however, with a shift in focus to the assessment and maximisation of intervention fidelity. Alongside needs to be consideration of multi-component and multi-setting approaches, and crucially how such complex approaches are evaluated. Despite the ineffective findings we need to continue to attempt to positively change children's physical activity behaviour and encourage the development and implementation of school-based interventions in practice, with accompanying process evaluations.

7.5 Recommendations for research

Recommendations for research specific to each individual analysis are included within the chapter discussions. Some of these recommendations include research to determine the population health impact of differences in VPA observed, determine approaches of how to increase VPA equitably and determine whether school-based interventions are effective within the school day. This section instead outlines overarching and cross-cutting recommendations for future studies that emerged from the totality of the research I conducted.

Future research investigating the effectiveness of physical activity interventions and components on VPA and MPA independently would add value to the literature. The analyses I present in this dissertation are split between investigating VPA vs MPA (within the observational analyses) and the use of the aggregate measure of MVPA (within the intervention analyses). This difference was due to key research gaps across both topics. The effectiveness and equity of school-based interventions on full day MVPA was not yet established and thus required addressing prior to investigating potential differences in effectiveness by VPA vs MPA. While, I would have additionally asked authors to re-analyse VPA and MPA separately, in practice this is an immense request and deemed likely to affect the number of positive responses. Analyses and reviews evaluating both existing physical activity behaviour split by MPA and VPA, alongside the impact of interventions independently on MPA and VPA, would be valuable.

Future research that aims to understand in greater detail the intensity differences between socioeconomic groups of children would also benefit from analysis of the entirety of a child's activity intensity profile alongside the traditional application of cut points as described above. The application of accelerometer cut-points removes individual variation in the intensity patterning of physical activity. Two children can have significantly different activity intensity amounts by falling just above versus below an accelerometer cut-point. In retrospect, this is an approach I would have explored to add greater value to my findings. Investigation of the whole spectrum of physical activity intensities is possible through the application of new statistical techniques such as multivariate pattern analysis.[346] Another option is an intensity gradient analysis, which alongside average acceleration, presents a complementary description of a child's entire activity profile and facilitates investigation of the relative importance of intensity and volume of activity for a given health outcome.[347] These approaches have emerged in recent years after I had started my research and could offer substantial value for future research investigating differences in physical activity.

Qualitative and mixed methods evaluations are needed in greater number to better understand both the factors driving socioeconomic differences in physical activity and why interventions are not working as intended. The quantitative approach I took across the epidemiological analyses tells us very little about why there are differences in the intensity patterning of physical activity behaviour between children. We need to better understand the underlying factors including barriers, habits, attitudes and beliefs, as well as how this differs between contexts, to be better able to design and develop effective interventions. Research to determine if particular activity behaviours underestimated or unable to be captured by accelerometer measurement (e.g cycling or contact sports) are patterned by equity characteristics would also be constructive for future analyses. Furthermore, as discussed, alongside a better understanding of current behaviour, we also need to conduct qualitative and mixed methods process evaluations in conjunction with every intervention evaluation, to develop an understanding of intervention implementation processes including how program components can be optimised across settings and contexts.

The two-staged systematic review I conducted (Chapter 5 and 6) was only able to address comparative differences in effect between socioeconomic groups and the gender of children within the same intervention study. Greater understanding on the comparative effectiveness of interventions targeted specifically at socioeconomically deprived populations of children and those that are universal (e.g. are designed to influence the entire social gradient of children) are needed. While it is likely that the optimum population preventative strategy incorporates a tiered combination of both targeted and universal approaches, the optimal balance for the greatest impact both on overall physical activity and reduction in inequalities is unclear. The ability to address these questions and to assess both overall and subgroup effects necessitates a coordinated effort towards high-quality experimental studies.

Finally, analyses and findings included within this dissertation illustrate the value of work towards greater research transparency, including the broader availability of data and better enforcement of trial registries. As demonstrated by the DEDIPAC analysis, large heterogenous datasets of individual level data add substantial value for maximising sample sizes and enabling appropriately powered subgroup and equity analyses. Further steps to the broader availability of harmonised datasets, such as the International Children's Accelerometery Database (ICAD), would continue to add substantial value to the field.[345] The positive responses received from both sets of data requests was very encouraging. However, within the in-depth review (presented in chapter 6) this process highlighted the presence of selective outcome reporting within interventions and raised a need for more work towards better systems to minimise bias. This issue is highlighted by two included trials that despite outlining MVPA as the outcome of interest in the trial registries concluded positive effectiveness through focusing on the statistically significant effect of the intervention on LPA,[320] and the activity of girls on the weekend,[348] respectively.

Despite the successful establishment of trial registries, there is currently no systematic structure to hold intervention authors responsible for the actions specified in the initial trial registration protocol. Without procedures in place that require intervention authors to reflect and report on deviations from their protocol when submitting to journals, it will remain easy for authors to publish findings inconsistent with their original registration. Research on consistency across intervention analyses and reporting from protocols to publications would be constructive in pushing stakeholders, including journals, to establish better systems and protocols to enforce transparency and the trial registration system. Analogous systems should be considered and developed with regards to observational analyses. The majority of observational studies are not prospectively registered despite representing a large proportion of published health related research,[349] and being highly susceptibility to publication and reporting bias.[349] While registries exist, similar enforcement systems are needed to shift the research field to regularly use them and stick to protocol plans.

7.6 Conclusion

Overall this dissertation reveals socioeconomic differences in the accumulation and patterning of children's physical activity behaviour, with no evidence that intervention efforts are influencing these inequalities.

The socioeconomic differences observed are through the intensity patterning of children's physical activity behaviour, which mirror parallel inequalities in childhood obesity. Collectively, this work suggests that overall international focus on promotion of MVPA may be masking meaningful inequalities in the relative contributions of VPA and MPA.

Research on existing physical activity promotion efforts demonstrated a widespread scarcity of consideration for equity within intervention evaluations. Subsequent analyses exposed that a subset of school-based multicomponent interventions are ineffective for all participants, by gender and SEP. In efforts to combat rising and widening childhood obesity rates, these findings demonstrate a need for the assessment and maximization of implementation fidelity across intervention efforts.

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9 APPENDICES

Appendix 1: Academic outputs

Peer review publications

Love R, Adams J, Sluijs EMF Van. Are school-based physical activity interventions effective and equitable? A meta-analysis of cluster randomized controlled trials with accelerometer-assessed activity. *Obesity Reviews*. 2019;1-12. doi:10.1111/obr.12823.

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Love R, Atkin A, Adams J, van Sluijs EM. Socio-economic and ethnic differences in children's vigorous intensity physical activity: a cross-sectional analysis of the UK Millennium Cohort Study. *BMJ Open*. 2019;In Press.

Love R, Adams J, van Sluijs EMF, Foster C, Humphreys D. A cumulative meta-analysis of the effects of individual physical activity interventions targeting healthy adults. *Obesity Reviews*. 2018;(6). doi:10.1111/obr.12690.

Corder K, Winpenny EM, Love R, Brown HE, White M, van Sluijs EM. Change in physical activity from adolescence to early adulthood: a systematic review and meta-analysis of longitudinal cohort studies. Br J Sports Med. 2017 Dec 4;

Conference abstracts and presentations

Love R, Adams J, van Sluijs EMF. Are school-based physical activity interventions effective and equitable? A systematic review and meta-analysis of cluster randomised controlled trials. *Lancet*. 2018;392:S53. doi:10.1016/s0140-6736(18)32174-3.

Love R, Adams J, Foster C, van Sluijs EMF, Humphreys D (2017). Are we there yet? A cumulative meta-analysis of the accumulation of evidence for physical activity. Journal of Epidemiology and Community Health Sep 2017, 71 (Suppl 1) A42; DOI: 10.1136/jech-2017-SSMAbstracts.83

Love R. Inequality in children's physical activity behaviour and interventions. Selected Student Keynote Presentation: International Society for Behavioural Nutrition and Physical Activity Annual Meeting. June 2018, Hong Kong (oral presentation).

Love R, Adams J, van Sluijs EM (2018). Are the effects of school-based interventions effective and equitable across gender and socioeconomic groups? International Society for Behavioural Nutrition and Physical Activity Annual Meeting. June 2018, Hong Kong (poster).

Love R, Adams J, van Sluijs EM (2018). Socio-economic and ethnic differences in intensity of MVPA in children: a cross sectional analysis of the UK Millennium Cohort Study. International Society for Behavioural Nutrition and Physical Activity Annual Meeting. June 2018, Hong Kong (poster).

Love R. (2017). Urbanization and obesity: a case study of Soweto, South Africa. Future Cities Annual Conference 'Growing Well', July 18th 2017, Cambridge UK

Love R, Adams J, van Sluijs EM (2017). Equity effects of children's physical activity interventions: a systematic scoping review. International Society for Behavioural Nutrition and Physical Activity Annual Meeting. Victoria, Canada June 2017 (oral).

Love R, Adams J, van Sluijs EM (2016). A scoping systematic review exploring the equity effects of children's physical activity interventions. Annual UKCRC Health Centres Research Conference, University of East Anglia, Norwich, July 14th & 15th, 2016

Awards

Lancet Public Health Conference (Nov 2018) Belfast UK: Awarded runner up prize for best poster

ISBNPA 2019 Annual Conference (June 2018) Hong Kong: Selected to give a student keynote presentation

ISBNPA 2019 Annual Conference (June 2018) Hong Kong: Nominee for best student poster award

Cumberland Lodge Scholarship (2016-2018) Windsor, UK

Future Cities PhD Prize Fellowship (2016-2017) Cambridge, UK

obesity reviews

doi: 10.1111/obr.12690

Obesity Prevention

A cumulative meta-analysis of the effects of individual physical activity interventions targeting healthy adults

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Summary

Despite a large and increasing evidence base on physical activity interventions, the high rates of physical inactivity and associated chronic diseases are continuing to increase globally. The purpose of this cumulative meta-analysis was to investigate the evolution of randomized controlled trial evidence of individual-level physical activity interventions to asses if new trials are contributing novel evidence to the field. Through a two-staged search process, primary studies examining the effects of interventions targeted at increasing physical activity within healthy adult populations were pooled and selected from eligible systematic reviews. Cumulative meta-analyses were performed on effect sizes immediately post-intervention (n = 62), and for long-term behaviour change (≥12-month post-baseline; n = 27). Sufficiency and stability of the evidence was assessed through application of pre-published indicators. Meta-analyses suggest overall positive intervention effects on physical activity. The evidence base for effectiveness immediately post-intervention reached levels of sufficiency and stability in 2007; and for long-term follow-up in 2011. In the time since, intervention effectiveness has not substantially changed, and further trials are unlikely to change the direction and magnitude of effect. Substantial evidence exists demonstrating that physical activity interventions can modify individual behaviour in controlled settings. Researchers are urged to shift focus towards investigating the optimization, implementation, sustainability and cost-effectiveness of interventions.

Keywords: Cumulative analysis, physical activity, scientific progress, systematic review.

Introduction

Physical inactivity is the fourth leading risk factor for global mortality (1). Worldwide, 31.1% of adults are physically inactive, which is projected to cause 5.3 million of the 57 million deaths worldwide, accounting for 9% of premature mortality and 6–10% of all deaths from major non-communicable diseases (2). It is estimated that a decrease in population level physical inactivity by only 10% would prevent half a million deaths each year (3). A recent analysis of 130,000 individuals revealed across 17 high, middle and low income countries higher levels of physical activity are consistently associated with a lower risk of mortality and cardiovascular disease (4). Alongside physical inactivity being an independent risk factor for cardiovascular disease, it further compounds the mortality risk through its association with obesity (5). Thus, increasing physical activity offers a simple and low-cost strategy of tackling rising rates of both obesity and chronic disease globally. In response to mounting evidence of these associations, the World Health Organization targets for physical activity, together with the United Nation's goals on non-communicable disease, have led to increasing adoption of national policies and recognition for the promotion of physical activity as a key element of efforts to improve the health of populations (6). Accordingly, over the last two decades, a wide range of interventions have been developed and employed in efforts to improve population levels of physical activity. Alongside, a

Table 1 Description of inclusion and exclusion criteria for Phases 1 (systematic review) and 2 (primary study) selection process

	Included	Excluded
Phase 1: systematic reviews		
Population	Reviews that included studies targeted at a general adult population (between 16 and 65 years)	Reviews with a central focus on the inclusion of studies targeted at participants with a medical condition
Intervention	Randomized controlled trials (RCTs) were eligible for inclusion in the review	
Study design	Reviews following an identified systematic process	Narrative and other non-systematic reviews that did not outline a systematic process for identifying and synthesizing studies
Phase 2: primary studies		
Population	Targeted at the general adult population with participants with a mean age greater then 16, less than 65 years Participants must have been free from pre-existing medical conditions or with no more than 10% of subjects with pre-existing medical conditions	Targeted at children (<16 years) and elderly individuals (>65 years) Study population with greater than 10% of subjects with pre-existing medical conditions Trials where the mean baseline BMI (kg/m^2) was above 30 (obese BMI classes)
Intervention	All physical activity interventions explicitly aimed at promoting change in the behaviour of participants at the individual level	Environmental changes, policy approaches and mass media campaigns
Study design	RCTs in which individuals were allocated individually or by cluster Active intervention arms must have been compared with a control arm (standard or usual care) or wait list control condition	All non-randomized designs All qualitative studies RCTs only comparing two active intervention
Outcomes	Reported continuous measure of physical activity with at least one time-point post-baseline	Those that did not report subjectively or objectively measured physical activity as a continuous, outcome measure
Publication type	Peer reviewed journal article	Conference abstract, study protocol, report, dissertation, book
Publication year	Any year	N/A
Publication language	English	Any other language

BMI, body mass index; RCTs, randomized controlled trial.

in primary studies, where available, we extracted this from published reviews that had utilized author data requests to clarify outcome values (10,15,16). For trials in which multiple intervention arms were presented compared with a single comparison group, the conditions were collapsed into a single mean intervention effect through calculation of a pooled mean and SD (as outlined in section 7.7.3.8 of the Cochrane Handbook) (17).

Intervention effects for outcome measures were calculated and expressed as standardized mean differences (SMDs), based on Hedges's adjusted *g* and its 95% confidence intervals (95% CI) (18). Because included studies measured physical activity across a variety of scales, SMD, calculated as the observed difference in means relative to an estimate of the SD, was used. Hedge's *g* was selected as the index of mean difference as it is the preferred approach when the majority of included studies have small sample sizes with comparably greater standard errors (19).

To assess differences in the accumulation of evidence for behaviour change immediately following an intervention trial and long-term behaviour change, two separate cumulative meta-analyses were conducted. The first, intervention effect at the follow-up time point closest to intervention end, included all trials in the review. The second included only those trials reporting assessments at least 12-month post-baseline. The cumulative meta-analysis provides cumulative pooled estimates and 95% CIs. As studies are successively added, the overall SMD and 95% CIs are recalculated providing evidence of the evolution of intervention effects over time. To assess the sequential contributions of trials and evaluate changes in effectiveness over time, studies were added alphabetically by year of publication to a random-effects models using the *metacum* user written command in STATA version 14.0.

Random effects models, based on the method of moments, were used under the assumption that the true effect sizes estimated by individual studies were drawn from a distribution of true effects rather than a single value, and an expectation of substantial heterogeneity given the differences in interventions eligible for inclusion (20). Given that random effect models can overestimate intervention effects in comparison to fixed effect models, a comparison of models can reveal the presence of small study effects that may result from publication or other biases. As both fixed (Mantel Haenszel) and random effects (DerSimonian and Laird) models produced comparable results, all analyses are presented using random effects estimates.

To address the question of whether and when sufficient evidence had been accumulated that the addition of further trials would not change established conclusions, Muellerleile's indicators of sufficiency and stability were applied to both cumulative meta-analyses (13). As defined by Muellerleile, sufficiency of the evidence was determined through evaluation of the failsafe ratio as each new trial was added to the cumulative meta-analysis. The failsafe ratio is a measure of the number of trials with null results required to make the meta-analytic result non-statistically significant (failsafe number), versus 5× (+10) the number of trials already available (Rosenthal standard). A failsafe ratio exceeding 1 indicates that there is sufficient evidence that additional research is unlikely to change the existing conclusion. Stability was assessed by calculating the cumulative slope of the regression line of the cumulative meta-analysis over time; when this becomes less than 0·005, it is suggested that the combined evidence has reached stability.

Results

Figure 1 shows the trial identification process, which identified 62 unique trials published up to 2013 (Data S2 and S3 provide reference lists of included and excluded studies). Of the 62 unique trials, 27 provided adequate data for inclusion in the long-term behaviour change analysis.

A summary of intervention characteristics is outlined Table 2 . The mean participant age in studies was 47.2 years (SD: 9.5) and 67% of participants were female. The included trials took place predominately in home (48%) and primary care (27%) settings, with fewer implemented in community (15%) and

Table 2 Characteristics of included studies

	No.	(%)		No.	(%)
Country			Delivery format		
United States	37	59.7	Virtual	22	35.5
United Kingdom	8	12.9	In person	19	30.6
Netherlands	5	8.0	Both	21	33.9
Australia or New Zealand	6	9.7	Delivery method		
Other	6	9.7	Individual	48	77.4
Setting of intervention			Group setting	11	17.7
Community	9	14.5	Frequency of intervention contact		
Home	30	48.4	Monthly or more	19	30.6
Primary care	17	27.4	Repeated less then monthly	30	48.4
Workplace	6	9.7	Once only	13	21.0
Measurement tool			Follow-up time		
Objective (e.g. accelerometer)	14	22.6	Greater than 6 months	41	66.1
Subjective (e.g. questionnaire)	48	77.4	Less than 6 months	21	33.9
Continuous characteristics	Mean	SD		Mean	SD
Participant percentage male	32.8	26.7	Intervention duration	21.1	16.9
Mean age	47.2	9.5	Follow-up time (weeks)	26.4	21.6

SD, standard deviation.

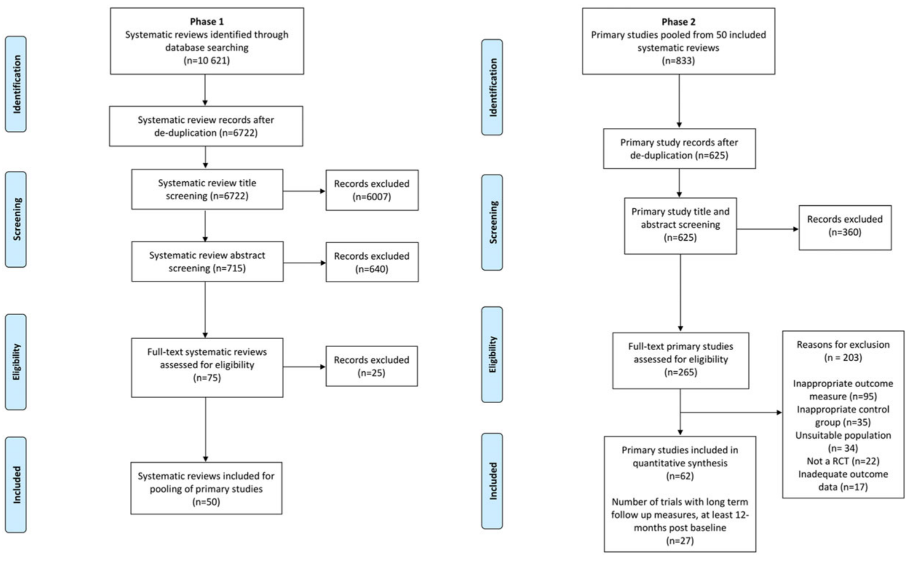

Figure 1 Study selection. [Colour figure can be viewed at wileyonlinelibrary.com]

workplace settings (10%). Interventions were delivered predominately on an individual basis (77.4%) as opposed to through group settings (17.7%). As outlined, interventions were spread across various modes of delivery (virtual, in-person). Subjective forms of physical activity measurement (primarily through questionnaire) was utilized substantially more than objective measurement (77% vs. 23%).

Figure 2 shows the cumulative meta-analysis of post-intervention effect sizes (n = 62). Early trials conducted throughout the 1980s and 1990s demonstrated a high degree of heterogeneity, with the first published results revealing statistically significant, positive effects. However, the conduct of additional trials weakened the initial evidence of effectiveness, with the overall effect no longer being significant by the ninth trial. Two trials in 1997 and 1999 reporting harmful, negative intervention effects contributed to this decrease in effect size. The overall effect regains statistical significance following the addition of the 33rd trial in 2007. According to the pre-established thresholds (Data S4), a sufficient and stable body of evidence with the potential to change the physical activity behaviour of participants immediately following intervention implementation, was achieved in 2007 with the addition of the 39th trial. Since then, we identified 23 further RCTs were reported up untill to 2013.

When the analysis was restricted to interventions with physical activity measurements at least 12-month post-baseline (n = 27), the thresholds of sufficiency and stability were not met until later. As displayed in Figure 3, similarly to the post-intervention analysis, early effects demonstrated large amounts of heterogeneity with a steadily decreasing effect as subsequent interventions are added. While a statistically significant overall effect was achieved in 2001, the combined thresholds of sufficiency and stability are not met until 2011 with the addition of the 23rd trial (Data S5). Only four further trials assessing long-term behaviour change had been reported after this point.

Discussion

This cumulative meta-analysis of individual-level physical activity interventions demonstrates that we have strong randomized evidence that physical activity levels can be improved and maintained. Estimates of post-intervention effects and long-term behaviour change have not changed substantially since 2007 and 2011, respectively, and additional trials are increasingly unlikely to change these stabilized findings. In the time following the attainment of predetermined thresholds of sufficiency and stability for post-intervention effects, we identified 23 further RCTs published to 2013. Although not included in the review, further intervention trials have been conducted and published since we ran our searches (21–23).

To our knowledge, this is the first cumulative meta-analysis of physical activity interventions. Overall, the results question the need for further trials testing the short-term effectiveness of individual physical activity interventions in healthy adult populations in highly controlled settings. The attainment of thresholds of sufficiency and stability, yet lack of impact on a population scale, indicate a need for a shift in research focus from controlled effectiveness trials to the optimization of interventions that effectively maintain behaviour change over the long term, within real world settings. Our results reinforce prior calls for a shift from the repetition of individual physical activity trials to focus on the sustained effects of interventions in practice (8). This should include adequate consideration for cost-effectiveness to enable identification of interventions that achieve maximum population health benefits relative to cost (24).

To build knowledge regarding how to optimize interventions to achieve long-term behaviour change within populations is a need for critical consideration of the decision making processes around what we evaluate. In theory, the decision to develop a trial to evaluate a new physical activity promotion intervention is determined by the ability of the trial to add value and change current knowledge and practice (25). Thus, ideally, new trials should build on prior evidence and through a cumulative process lead to the development of more effective interventions. However, evidence suggests that the norm is to reinvent programs and approaches, rather than directly building and innovating on previous findings (26).

Continuing to test interventions against standard, no treatment control conditions, provides little information about the relative effects of different interventions and intervention components, restricting the ability to build on prior knowledge. Given the sufficiency and stability of evidence within highly controlled settings, yet rising population levels of physical inactivity, there needs to be a shift towards developing evaluations to help us understand what works. Traditional two-arm RCTS assess the effectiveness of the whole intervention versus control, without an ability to determine which intervention components and settings are, or are not, contributing to the effect. This evaluative approach continues to persist; 80% of RCTs registered between 2010 and 2012 were composed of two groups (27). Given that the majority of physical activity interventions, like most behavioural trials, are composed of multiple components, continuing to utilize the traditional two-arm RCT restricts opportunity to advance effectiveness and secondly understand effects across various settings.

The identification of the key active ingredients in interventions is crucial towards generating knowledge that will enable the optimization and development of more effective interventions. Commonly, researchers perform exploratory analyses posthoc to understand differences in intervention components and settings. However, these tests are subject to confounding. Additionally, systematic reviews

Appendix 1: Academic Outputs

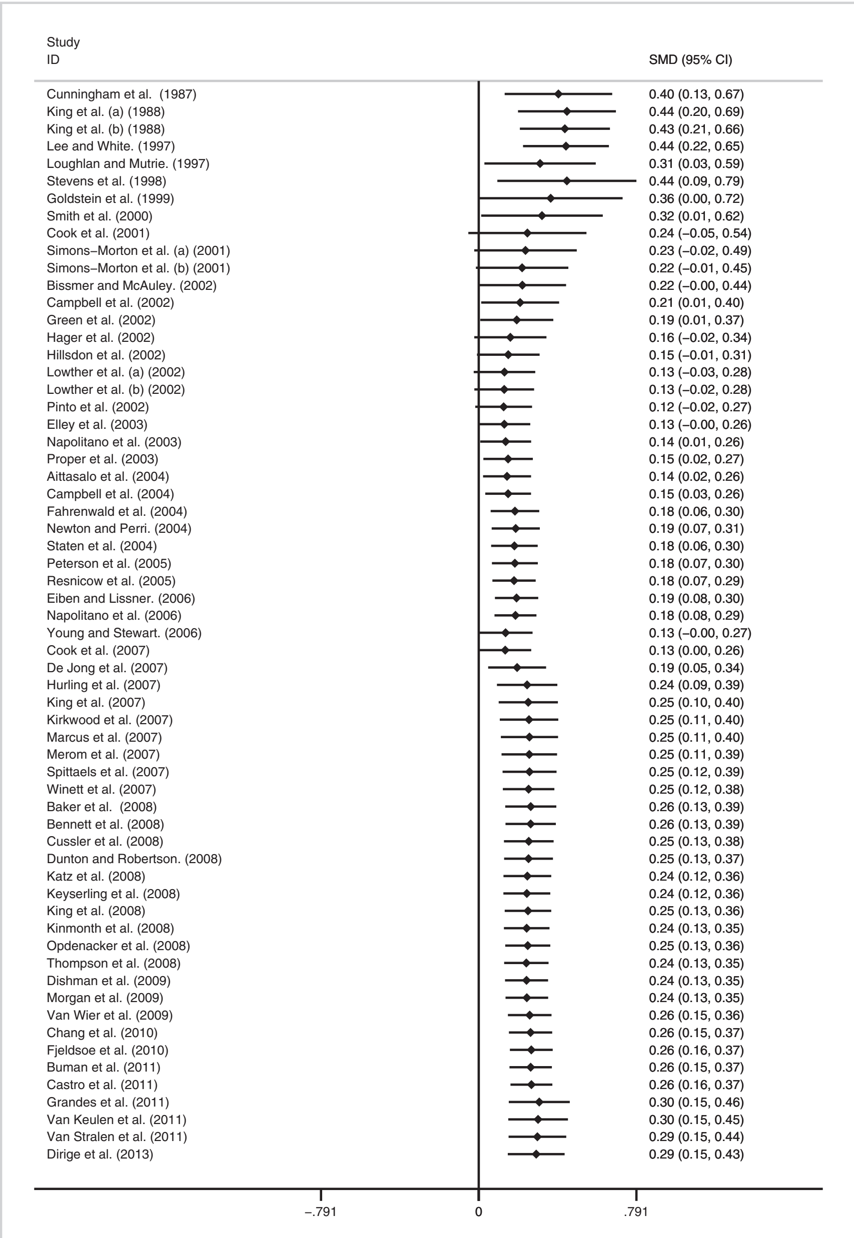

Figure 2 Cumulative meta-analysis of intervention effect immediately post-intervention.

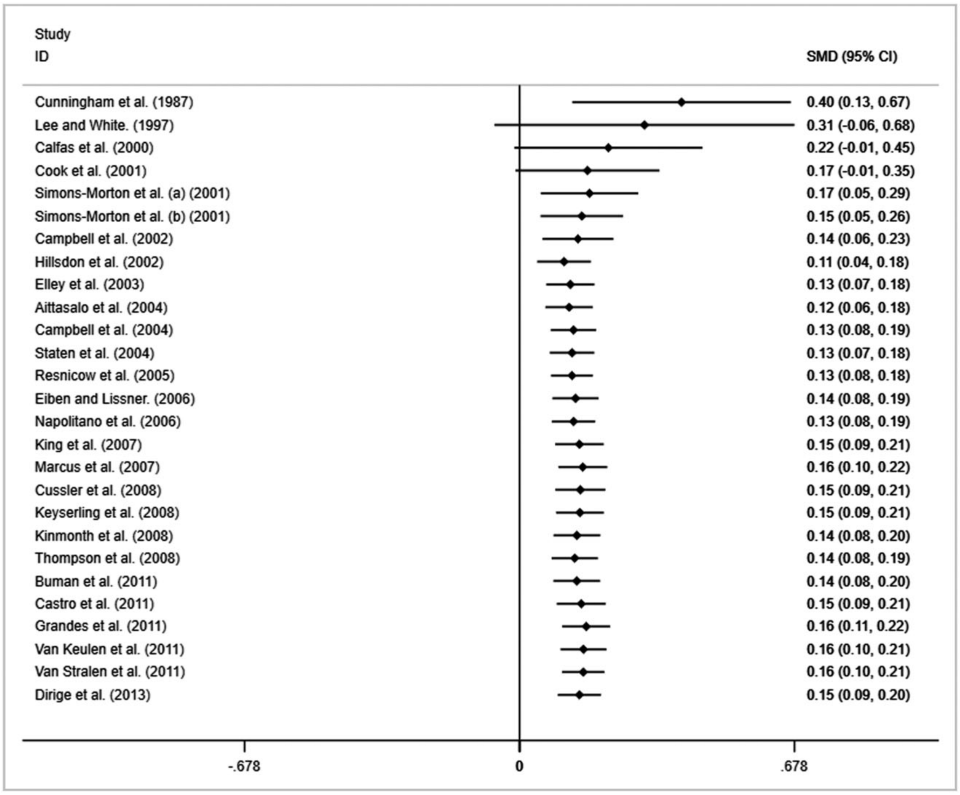

Figure 3 Cumulative meta-analysis of intervention effect on long-term behaviour change (trials with follow-up at least 12-month post-baseline).

and accompanying meta-regressions are regularly used to understand mediators and moderators of intervention effectiveness. Yet, the use of meta-regressions to make inferences about individual level change, using study level information are, and will continue to be, at risk of ecological fallacy (28). Full and fractional factorial design trials and multi-arm multi-stage trials are methods of evaluation that enable multiple intervention components to be assessed simultaneously (29,30). This includes isolation and testing both of characteristics of the intervention program, and aspects of implementation and delivery. These methods enable researchers to test intervention component hypotheses without the need for a full confirmatory trial until there is sufficient indication of effectiveness. Evaluating frameworks, including the multi-phase optimization strategy, have been developed and tested for optimization (31). While multi-arm and factorial methods have high short-term resource requirements, we suggest that they may have the large long-term savings in comparison to conducting sequential large-scale trials. Given the influence of research funding requirements on researcher actions, it is crucial that funders recognize the long-term benefits of investment in alternative research methods and support a shift in research towards newer methods of evaluation that require longer planning, implementation and evaluation times. Alongside, we highlight the use of individual level meta-analyses and regressions as a non-biased alternative to traditional meta-analyses. While requiring significant researcher cooperation, the output is promising as demonstrated by InterConnect, a recently developed global database enabling federated meta-analyses of the determinants of diabetes and obesity (32).

In light of the sufficiency and stability of the large evidence base of RCTs that has amassed since 1987, the results of this review raise a collective need for a new approach to intervention development and optimization focused on the scaling up and population impact of interventions. While the considerably more recent achievement of thresholds for longer term outcomes is promising, suggesting that over time we have moved towards a focus on longer term outcomes, the overall results direct a need to shift focus. The opportunity costs of continuing with the current repeated generation of two-arm RCTs on the effects of interventions in highly controlled settings, without systematic consideration of longer term implementation within broader systems, is large for participants, researchers, funders and health systems. As a field, if we want to have a meaningful impact at a population scale, we need to work to fill the knowledge gap for the long-term sustainability and effectiveness of evidence-based practice and research (33). This includes addressing challenges in the implementation and embedment of programs within societal and governmental systems.

The two-stage approach of this review has inherent weaknesses. Reliance on previous systematic reviews for the pool of primary data is subject to bias. In addition, only a proportion of studies were double coded and, therefore, we cannot rule out some inaccuracies due to coding. While we recognize that the literature searches were conducted in spring 2015, the inclusion of additional studies through up-to-date searches would only serve to further confirm the findings of our analyses. The measures of sufficiency and stability reported for both short and longer term effects suggest that multiple large trials with a drastically negative effect would be needed to invalidate our findings.

We acknowledge the multiple methodological options available for the evaluation of cumulative meta-analyses. Given the lack of consensus on which of these are 'best', we selected the option we felt was most appropriate for this public health question. In post hoc analyses, we applied an alternative method which produced similar findings and would lead to the same conclusions as are currently drawn (34). Lastly, the nature of cumulative meta-analysis as a sequential procedure in which an updated meta-analysis is performed each time a new trial is added to the analysis, brings with it issues and risks with respect to repeated testing and inflated type one error (35).

In examining the accumulation of evidence, this paper is not suggesting that the 23 RCTs published after the thresholds of sufficiency and stability were achieved were not worth conducting. We recognize that the evidence generated from additional RCTs may resolve uncertainties for specific settings, mechanisms of intervention delivery and effectiveness. Rather, this paper suggests that a research field often establishes answers to research questions sooner than collectively realized and re-emphasizes the importance of reflecting on the accumulated evidence base before proceeding with the generation of new evidence. In the face of the global inactivity pandemic, these results suggest that researchers must shift focus towards the development and optimization of interventions that can be effectively scaled-up to achieve long-term behaviour change across populations.

Conflict of interest statement

No conflict of interest was declared.

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Supporting information

Additional Supporting Information may be found online in the supporting information tab for this article. https://doi.org/10.1111/obr.12690

Data S1: Database Search Strategies
Data S2: Included primary studies and systematic reviews
Data S3: Excluded studies and reasons for exclusion
Data S4: Post intervention Cumulative Meta-analysis
Data S5: Long term follow-up Cumulative Meta-analysis
Table 1: Reasons for exclusion of primary studies
Table 2: Application of indicators of sufficiency and stability
Table 3: Application of indicators of sufficiency and stability
Figure 1. Application of indicator or of sufficiency (Failsafe Ratio)
Figure 2. Application of indicator of stability (Cumulative Slope)
Figure 3. Application of indicator of sufficiency (Failsafe Ratio)
Figure 4. Application of indicator of stability (Cumulative Slope)

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APPENDIX 2: CHAPTER 2

A.2.1 Multivariable linear regression models for mean minutes of VPA and MPA overall, weekdays and weekend days, by ethnic subgroups (n=5,172) within the Millennium Cohort Accelerometer Study, 4th follow-up (2008-09)

By ethnic group			note: .01 - ***; .05 - **; .1 - *;		
VPA (mins/day)			**MPA (mins/day)**		
All valid days					
ref cat: White	**coef**	**se**	**ref cat: White**	**coef**	**se**
Mixed	1.468*	0.782	Mixed	-2.223**	1.036
Indian	0.738	0.984	Indian	-3.938***	1.168
Pakistani & Bangladeshi	-3.344***	0.673	Pakistani & Bangladeshi	2.089**	0.900
Black or Black British	-1.675	1.168	Black or Black British	3.009***	0.988
Other ethnic group	-2.267**	0.966	Other ethnic group	1.087	1.728
MPA (mins/day)	0.584***	0.018	VPA (mins/day)	0.814***	0.020
Weartime (mins/day)	0.000	0.003	Weartime (mins/day)	0.014***	0.003
Age (yrs)	1.079**	0.535	Age (yrs)	-1.876***	0.657
Sex of participant	0.700**	0.292	Sex of participant	-5.064***	0.320
Season of measurement	0.042	0.165	Season of measurement	-1.727***	0.177
_cons	-14.150***	4.293	_cons	41.945***	5.295
r2	0.515		r2	0.565	
Number of observations	5,172		Number of observations	5,172	
Weekdays					
ref cat: White	**coef**	**se**	**ref cat: White**	**coef**	**se**
Mixed	1.569*	0.871	Mixed	-2.001*	1.138
Indian	0.578	0.923	Indian	-3.463***	1.106
Pakistani & Bangladeshi	-3.451***	0.743	Pakistani & Bangladeshi	1.998**	0.965
Black or Black British	-2.076*	1.223	Black or Black British	3.098***	1.167
Other ethnic group	-3.069***	1.145	Other ethnic group	1.888	1.891
Weekday MPA (mins/day)	0.584***	0.022	Weekday VPA (mins/day)	0.789***	0.021
Weekday weartime (mins/day)	-0.000	0.003	Weekday weartime (mins/day)	0.015***	0.003
Age (yrs)	0.951*	0.576	Age (yrs)	-1.331*	0.703
Sex of participant	0.739**	0.311	Sex of participant	-5.066***	0.332
Season of measurement	0.026	0.171	Season of measurement	-1.693***	0.184
_cons	-12.724***	4.553	_cons	37.062***	5.484
r2	0.497		r2	0.543	
Number of observations	5,172		Number of observations	5,172	
Weekend days					
ref cat: White	**coef**	**se**	**ref cat: White**	**coef**	**se**
Mixed	0.434	0.944	Mixed	-2.131	1.484
Indian	0.757	1.499	Indian	-4.463**	1.785
Pakistani & Bangladeshi	-3.001***	0.692	Pakistani & Bangladeshi	2.024*	1.198
Black or Black British	-0.035	1.736	Black or Black British	1.766	1.390
Other ethnic group	-0.141	1.091	Other ethnic group	-1.339	2.059
Weekend MPA (mins/day)	0.540***	0.016	Weekend VPA (mins/day)	0.956***	0.023
Weekend weartime (mins/day)	-0.002	0.002	Weekend weartime (mins/day)	0.017***	0.003
Age (yrs)	1.389**	0.689	Age (yrs)	-3.486***	0.918
Sex of participant	0.103	0.331	Sex of participant	-4.643***	0.466
Season of measurement	-0.205	0.217	Season of measurement	-1.483***	0.270
_cons	-12.259**	5.199	_cons	48.524***	7.067
r2	0.546		r2	0.572	
Number of observations	5,172		Number of observations	5,172	

A.2.2 Multivariable linear regression models for mean minutes of VPA and MPA overall, weekdays and weekend days, by level of maternal education (n=5,172) within the Millennium Cohort Accelerometer Study, 4th follow-up (2008-09)

By level of maternal education			note: .01 - ***; .05 - **; .1 - *;		
VPA (mins/day)			**MPA (mins/day)**		
All valid days					
ref cat: No qualifications	**coef**	**se**	**ref cat: No qualifications**	**coef**	**se**
Low	1.314**	0.559	Low	-0.950	0.836
Medium	1.653***	0.572	Medium	-1.483*	0.851
High	1.812***	0.532	High	-1.689**	0.815
Higher	2.957***	0.769	Higher	-2.738***	0.925
Overseas qual.	2.276*	1.314	Overseas qual.	-1.957	1.334
None of these	-0.448	0.674	None of these	1.978*	1.035
MPA (mins/day)	0.587***	0.018	VPA (mins/day)	0.815***	0.019
Weartime (mins/day)	-0.002	0.003	Weartime (mins/day)	0.014***	0.003
Age (yrs)	1.044*	0.543	Age (yrs)	-1.901***	0.656
Sex of participant	0.681**	0.297	Sex of participant	-5.043***	0.325
Season of measurement	0.081	0.164	Season of measurement	-1.736***	0.179
_cons	-14.404***	4.418	_cons	42.866***	5.471
r2	0.515		r2	0.567	
Number of observations	5,172		Number of observations	5,172	
Weekdays					
ref cat: No qualifications	**coef**	**se**	**ref cat: No qualifications**	**coef**	**se**
Low	1.314**	0.616	Low	-0.944	0.893
Medium	1.717***	0.628	Medium	-1.384	0.907
High	1.880***	0.585	High	-1.732**	0.869
Higher	3.045***	0.843	Higher	-2.708***	0.962
Overseas qual.	2.123	1.314	Overseas qual.	-2.293	1.407
None of these	-0.597	0.727	None of these	1.878*	1.116
Weekday MPA (mins/day)	0.588***	0.021	Weekday VPA (mins/day)	0.790***	0.021
Weekday weartime (mins/day)	-0.002	0.003	Weekday weartime (mins/day)	0.015***	0.003
Age (yrs)	0.910	0.584	Age (yrs)	-1.343*	0.697
Sex of participant	0.713**	0.316	Sex of participant	-5.038***	0.336
Season of measurement	0.067	0.170	Season of measurement	-1.703***	0.185
_cons	-12.864***	4.666	_cons	37.919***	5.647
r2	0.496		r2	0.545	
Number of observations	5,172		Number of observations	5,172	
Weekend days					
ref cat: No qualifications	**coef**	**se**	**ref cat: No qualifications**	**coef**	**se**
Low	1.335*	0.711	Low	-1.317	1.055
Medium	1.366*	0.736	Medium	-1.894*	1.112
High	1.627**	0.668	High	-1.711*	1.016
Higher	2.796***	0.884	Higher	-3.556***	1.194
Overseas qual.	2.694	1.714	Overseas qual.	-1.735	1.953
None of these	-0.065	0.868	None of these	2.348*	1.354
Weekend MPA (mins/day)	0.543***	0.016	Weekend VPA (mins/day)	0.955***	0.023
Weekend weartime (mins/day)	-0.002	0.002	Weekend weartime (mins/day)	0.017***	0.003
Age (yrs)	1.376**	0.698	Age (yrs)	-3.554***	0.927
Sex of participant	0.105	0.333	Sex of participant	-4.654***	0.467
Season of measurement	-0.171	0.219	Season of measurement	-1.495***	0.271
_cons	-13.489**	5.374	_cons	50.213***	7.259
r2	0.546		r2	0.575	
Number of observations	5,172		Number of observations	5,172	

A.2.3 Multivariable linear regression models for mean minutes of VPA and MPA overall, weekdays and weekend days, by annual household equivalised income (n=5172) within the Millennium Cohort Accelerometer Study, 4th follow-up (2008-09)

By household equivalised income			note: .01 - ***; .05 - **; .1 - *;		
VPA (mins/day)			MPA (mins/day)		
All valid days					
	coef	se		coef	se
Annual income/10000	0.579***	0.131	Annual income/10000	-0.976***	0.141
MPA (mins/day)	0.587***	0.018	VPA (mins/day)	0.812***	0.019
Weartime (mins/day)	-0.001	0.003	Weartime (mins/day)	0.014***	0.003
Age (yrs)	0.998*	0.540	Age (yrs)	-1.828***	0.654
Sex of participant	0.719**	0.299	Sex of participant	-5.109***	0.325
Season of measurement	0.103	0.166	Season of measurement	-1.772***	0.178
_cons	-14.095***	4.396	_cons	43.738***	5.339
r2	0.513		r2	0.566	
Number of observations	5,172		Number of observations	5,172	
Weekdays					
	coef	se		coef	se
Annual income/10000	0.613***	0.136	Annual income/10000	-0.990***	0.145
Weekday MPA (mins/day)	0.588***	0.022	Weekday VPA (mins/day)	0.786***	0.021
Weekday weartime (mins/day)	-0.002	0.003	Weekday weartime (mins/day)	0.015***	0.003
Age (yrs)	0.857	0.581	Age (yrs)	-1.272*	0.696
Sex of participant	0.753**	0.320	Sex of participant	-5.107***	0.336
Season of measurement	0.092	0.172	Season of measurement	-1.741***	0.184
_cons	-12.484***	4.629	_cons	38.716***	5.474
r2	0.494		r2	0.545	
Number of observations	5,172		Number of observations	5,172	
Weekend days					
	coef	se		coef	se
Annual income/10000	0.500***	0.162	Annual income/10000	-0.915***	0.210
Weekend MPA (mins/day)	0.542***	0.016	Weekend VPA (mins/day)	0.957***	0.023
Weekend weartime (mins/day)	-0.002	0.002	Weekend weartime (mins/day)	0.016***	0.003
Age (yrs)	1.346*	0.695	Age (yrs)	-3.477***	0.922
Sex of participant	0.140	0.334	Sex of participant	-4.701***	0.469
Season of measurement	-0.153	0.220	Season of measurement	-1.520***	0.272
_cons	-13.159**	5.327	_cons	50.629***	7.161
r2	0.545		r2	0.572	
Number of observations	5,172		Number of observations	5,172	

A.2.4 Multivariable linear regression models for mean minutes of VPA with additional adjustments for BMI z-score overall, on weekdays and on weekend days, by ethnic subgroups maternal education and household equivalised income (n=5149) within the Millennium Cohort Accelerometer Study, 4th follow-up (2008-09)

Ethnicity						
	All valid days		Weekdays		Weekends	
	coef	se	coef	se	coef	se
Mixed	1.400*	0.754	1.503*	0.831	0.364	0.961
Indian	0.484	0.989	0.330	0.932	0.522	1.512
Pakistani & Bangladeshi	-3.616***	0.626	-3.735***	0.693	-3.240***	0.668
Black or Black British	-0.769	1.072	-1.124	1.139	0.678	1.680
Other ethnic group	-2.668***	0.981	-3.508***	1.161	-0.421	1.097
MPA (mins/day)	0.579***	0.018	0.581***	0.021	0.536***	0.015
Weartime (mins/day)	-0.000	0.003	-0.000	0.003	-0.002	0.002
Age (yrs)	1.069**	0.530	0.947*	0.571	1.374**	0.686
Sex of participant	0.686**	0.290	0.733**	0.309	0.099	0.330
Season of measurement	-0.007	0.162	-0.006	0.169	-0.295	0.212
BMI zscore	-0.882***	0.126	-0.932***	0.129	-0.702***	0.167
_cons	-13.169***	4.221	-11.801***	4.495	-11.436**	5.144
r2	0.523		1		1	
Number of observations	5,149		5,149		5,149	

Maternal education						
	All valid days		Weekdays		Weekends	
	coef	se	coef	se	coef	se
Low	1.385**	0.558	1.413**	0.616	1.332*	0.706
Medium	1.806***	0.572	1.882***	0.629	1.508**	0.732
High	1.841***	0.532	1.929***	0.586	1.612**	0.666
Higher	2.990***	0.765	3.093***	0.839	2.815***	0.880
Overseas qual.	2.278*	1.367	2.139	1.373	2.675	1.747
None of these	-0.452	0.668	-0.587	0.720	-0.101	0.863
MPA (mins/day)	0.584***	0.018	0.586***	0.021	0.540***	0.016
Weartime (mins/day)	-0.002	0.003	-0.002	0.003	-0.002	0.002
Age (yrs)	1.037*	0.536	0.908	0.577	1.363*	0.695
Sex of participant	0.669**	0.294	0.707**	0.313	0.102	0.332
Season of measurement	0.032	0.161	0.035	0.168	-0.260	0.213
BMI zscore	-0.876***	0.136	-0.933***	0.140	-0.668***	0.171
_cons	-13.655***	4.342	-12.143***	4.602	-12.804**	5.323
r2	0.523		0.504		0.549	
Number of observations	5,149		5,149		5,149	

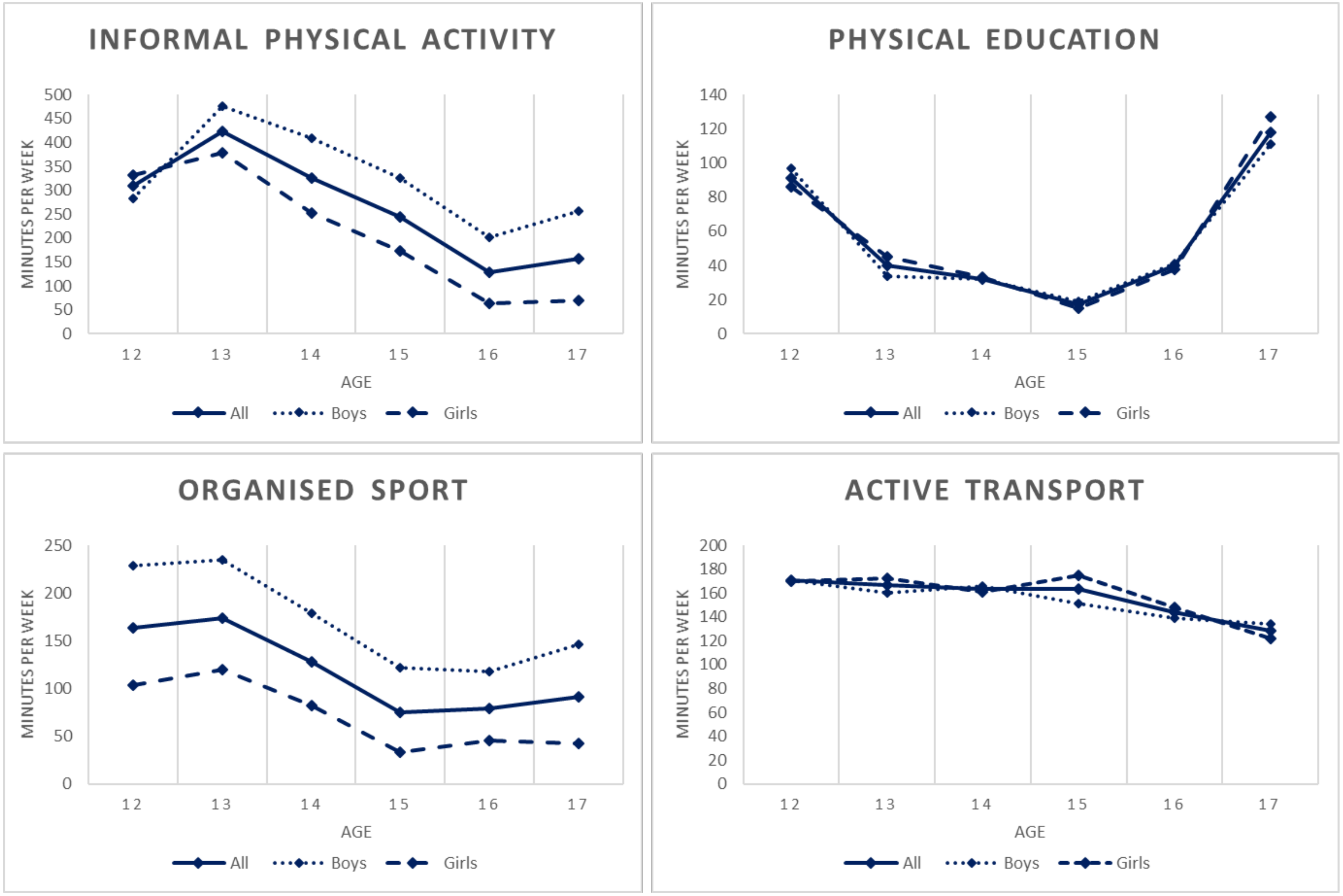
Household equivalised income						
	All valid days		Weekdays		Weekends	
	coef	se	coef	se	coef	se
Annual income/10000	0.579***	0.131	0.613***	0.136	0.500***	0.162
MPA (mins/day)	0.587***	0.018	0.588***	0.022	0.542***	0.016
Weartime (mins/day)	-0.001	0.003	-0.002	0.003	-0.002	0.002
Age (yrs)	0.998*	0.540	0.857	0.581	1.346*	0.695
Sex of participant	0.719**	0.299	0.753**	0.320	0.140	0.334
Season of measurement	0.103	0.166	0.092	0.172	-0.153	0.220
_cons	-14.095***	4.396	-12.484***	4.629	-13.159**	5.327
R2	0.513		0.494		0.545	
Number of observations	5,172		5,172		5,172	

A.2.5 Multivariable linear regression models for BMI z-score by minutes of daily VPA and MPA (n=5149) within the Millennium Cohort Accelerometer Study, 4th follow-up (2008-09), adjusted for age, sex and wear time

BMI z-score	**β-coeff**	[95% Conf	Interval]
Mean Minutes MPA/day	-0.002	-0.006	-0.001
Mean Minutes VPA/day	-0.012	-0.017	-0.007

APPENDIX 3: CHAPTER 3

A.3.1 Physical activity trends of Birth to Twenty analytic sample (N=1,065) from ages 12-17, overall, and split by gender



A.3.2 Two-stage hurdle models investigating the relationship between household socioeconomic status (score out of 10) and physical activity behaviour overall for all participants, and by gender for females and males in the Birth to Twenty Cohort, utilizing aggregated average physical activity across ages 12, 13 & 14 with asset data at age 13, and across 15, 16 and 17, with asset data at age 16

	Age 13 (PA avg of 12, 13, 14)					**Age 16** (PA avg of 15, 16, 17)				
	N	**Stage 1: Binary GLM**		**Stage 2: Non-Zero GLM**		**N**	**Stage 1: Binary GLM**		**Stage 2: Non-Zero GLM**	
		Odds ratio	*se*	*ℬ-coef*	*se*		*Odds ratio*	*se*	*ℬ-coef*	*se*
Informal Activity (mins/week)										
All participants	1155	*0.89*	*0.13*	**-8.25***	**3.01**	1593	***0.94****	***0.03***	**-8.67***	**2.23**
Males	541	*1.03*	*0.30*	6.37	4.64	771	*1.06*	*0.08*	-3.61	4.66
Females	614	*0.86*	*0.15*	**-15.34***	**3.93**	822	***0.91****	***0.04***	**-9.40***	**2.80**
Physical Education (mins/week)										
All participants	1155	***1.07****	***0.03***	-0.24	0.93	*1578*	***1.10*****	***0.03***	-0.11	0.26
Males	541	***1.11****	***0.05***	-0.44	1.43	*766*	*1.06*	*0.04*	-0.51	0.36
Females	614	*1.03*	*0.04*	0.07	1.23	*812*	***1.13*****	***0.04***	0.21	0.36
Active Transport (mins/week)										
All participants	1155	**0.60***	**0.03**	**-25.95***	**2.08**	1593	**0.70***	**0.03**	**-20.64***	**1.36**
Males	541	**0.56***	**0.05**	**-28.62***	**2.59**	771	**0.72***	**0.06**	**-18.27***	**1.92**
Females	614	**0.62***	**0.04**	**-24.43***	**2.35**	822	**0.69***	**0.04**	**-22.81***	**1.91**
Sport (mins/week)										
All participants	1155	1.07	0.05	-0.11	1.85	1593	1.04	0.03	1.47	1.21
Males	541	1.04	0.09	-4.39	3.43	771	0.94	0.04	-3.94	3.18
Females	614	1.09	0.06	0.74	2.39	822	**1.10***	**0.04**	**1.89**	**1.54**

Note: .01 - ***; .05 - **; .1 - *.

APPENDIX 4: CHAPTER 4

A.4.1 All studies included in the DEDIPAC children's accelerometry database

1. Study Name*	Yrs	Months	Country
ALSPAC	2003-07	All	United Kingdom
Ballabeina Study	2008-09	June-Sept	Switzerland
Belgium Pre-School Study	2006;08-09	Oct-March	Belgium
CHASE	2006-07	Jan-Feb	United Kingdom
COSCIS	2001-05	Oct-May	Denmark
EYHS (Denmark)	1997-98; 2003-04	All	Denmark
EYHS (Estonia)	1998-99	Aug-May	Estonia
EYHS (Norway)	1999-00	Feb-Oct	Norway
EYHS (Portugal)	1999-00	Jan-July	Portugal
EYHS SPAIN	2008-10	-	SPAIN
GINI	2011-14	All	Germany
Helena	2006-07	All	Austria, Belgium, France, Germany, Greece, Hungary, Italy, Spain, Sweden
IDEFICS	2007-2010	Sept-May	Italy, Estonia, Cyprus, Belgium. Sweden, Germany, Hungary, Spain
ISCOLE	2011-13	All	Finland
KISS	2005-06	May-Nov	Switzerland
LISA	2011-14	All	Germany
MAGIC	2006-07	Nov-May	United Kingdom
MAL-TA	2012	Jan-May	Malta
Odense Preschool	2009	May-June	Denmark
OPUS	2011	Aug-Nov	Denmark
PANCS	2005-06	All	Norway
PEACH	2006-09	Sept-July	England
Portugal	2008-09	All	Portugal
PRESTYLE	2009	-	Portugal
ProActive	2012-13	-	United Kingdom
SALTA Project	2010-11	Sept-June	Portugal
SPACE	2010	Apr-June	Denmark
SPEEDY	2007	Feb-July	United Kingdom
The Belgian Environmental PA study in Youth	2008-09	Oct-May	Belgium
The Gateshead Millennium Study	2006-07	Oct-Dec	United Kingdom

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A.4.2 Request sent to cohort authors

Dear Dr X,

My name is Rebecca Love. I am a PhD student at the CEDAR with Dr Esther van Sluijs and Dr Jean Adams, currently working in collaboration with Dr Ulf Ekelund and Dr Jostein Steene-Johannessen at the Norwegian School of Sports Science.

You previously provided data from the X trial as part of the DEDIPAC consortium on children's accelerometer-assessed physical activity. We are presently planning a further analysis that investigates if the intensity patterning of physical activity differs between socioeconomic groups of children across Europe. I attach a document that outlines the proposed analysis.

It would be extremely valuable to include data from the X trial in these analyses. To enable the inclusion of your study, we ask you to provide us with data on maternal education (using the ID numbers as when you submitted your data for the original PA paper), as well as details on how this data was collected. Similar to the previous analysis, the data will be stored, managed and processed as per the data policies of the Norwegian School of Sports Sciences.

Please send the data to Ulf Ekelund (ulf.ekelund@nih.no), copying in Jostein (jostein.steene-johannessen@nih.no) and myself (rel54@medschl.cam.ac.uk) (all ccd into this email). We ask that you send this by **Wednesday August 15th.** If this deadline is not possible please get in touch and we will do our best to accommodate inclusion of your study.

Please also contact me (rel54@medschl.cam.ac.uk) if you have any questions or if you have a co-author who would be better placed to provide this information.

Your time is greatly appreciated.

With best wishes,

Rebecca Love

Document attached to data request email

Research question of interest: Socio-economic patterning of physical activity intensities: are the current global recommendations of physical activity for children appropriate?

Data request: We are getting in touch to request maternal education from your study that was included in the data pooling for the DEDIPAC consortium. Below we have outlined the aim, background, proposed analysis strategy and offer of co-authorship. Please get in touch if you have questions or, as outlined in our email, are unable to meet the Wednesday August 15th deadline for receipt of data.

As a collaboration between the MRC Epidemiology Unit, University of Cambridge and Norwegian School of Sports Science, we plan to use data aggregated through the DEDIPAC consortium on children's accelerometer-assessed activity, alongside with maternal education data, to answer the two aims outlined below.

Aim of analysis:

To a) investigate if the intensity patterning of physical activity differs between socioeconomic groups across Europe and b) if this relationship differs between national contexts, welfare regimes and wealth distributions to help explain obesity inequalities.

Background: The World Health Organisation (WHO) recommends children accumulate 'at least 60 mins moderate-to-vigorous intensity physical activity (MVPA) daily'. The guidelines additionally recommend that vigorous activities are incorporated three times a week, but less emphasis is placed on this. Correspondingly, most physical activity research, national surveys and intervention trials utilize the aggregate measure of MVPA to quantify and study activity levels. The WHO upholds that this recommendation is relevant irrespective equity factors including the socioeconomic circumstances of individuals.[355]

Accumulating evidence indicates that the association between activity and adiposity is driven by intensity. Vigorous physical activity (VPA) has repeatedly been demonstrated to be more strongly associated with reduced waist circumference and lower adiposity risk, then sedentary time, moderate physical activity (MPA) or total physical activity.[77–81] Little is known about the prevalence and distribution of VPA in children. Considering the distinct characteristics of MPA (e.g. walking to school) and VPA (e.g. sport participation), it is conceivable differences exist between socioeconomic subgroups, which may help explain increasing inequalities in overweight/obesity prevalence.

Previous research using objectively measured activity has indicated no apparent socioeconomic patterning in children's adherence to the international MVPA guidelines.[41,185,186] In addition, time spent in MVPA only explains a small portion of the socioeconomic gradient in overweight risk present within UK children.[187] In an ongoing analysis of the UK Millennium Cohort Study we identified that children from socioeconomically deprived groups spent less time in VPA, when accounting for time spent in MPA, partially explaining the social disparities in overweight and obesity across subgroups of UK children. Similarly to the UK, many countries globally are experiencing widening obesity inequalities between advantaged and disadvantaged groups.

There is limited evidence and understanding of how different intensities of activity differ by individual and area-level socioeconomic circumstances[165]. We therefore aim to investigate if socioeconomic patterning of activity intensity exists across European Countries and may help to explain inequalities in childhood obesity. Secondly, we aim to examine if these associations vary across welfare regimes (conservative, social-democratic, mediterranean, liberal), Gross Domestic Product (GDP) and differences in national wealth distribution (via the Gini coefficient).

Inclusion criteria for studies:

Studies that meet the criteria outlined below will be included:

- The study is included in the DEDIPAC accelerometer database
- The study contains and is able to provide information on the maternal education of the study participant's parents (Preferably maternal education)
- In accordance with our institution's policy, the study did not receive food industry sponsorship
- Approval is received from study authors for use of data in this subsequent analysis

Maternal education

Given initial scoping work investigating socioeconomic data available within included DEDIPAC studies, we plan to use maternal education as our selected indicator of socioeconomic status. A decision on how to harmonize the data will be made dependent on the data available and received. Following the published process of harmonization of maternal education within ICAD studies (which make up 10 of the 30 total included studies), we aim to make this comparable to the following categories:

- '0' : Up to and including completion of compulsory education;
- '1' : Some post-compulsory education or vocational training;
- '2' : Completed undergraduate or postgraduate education

Analysis Plan:

Study leads will be contacted for approval for inclusion in this analysis. If in agreement they will be asked to send available maternal education data for their study. Following receipt of all maternal education data, this will be harmonized into categories. Data will be stored, managed and analysed at the Norwegian School of Sports Science.

Multivariable linear regression models will be fitted to analyse differences in absolute minutes of VPA across categories of maternal education, adjusted for MPA and mean accelerometer wear time, for each included study. Subsequently, through a meta-analysis approach, the B-coefficient and confidence intervals for each study will be combined into a forest plot. A separate meta-analysis will be run for B-coefficients & 95% confidence intervals for middle vs. low maternal education and high vs low maternal education. Next, we will investigate differences in the patterning of VPA through a series of subgroup analyses. These groupings will include national context, welfare state, tertiles of gross domestic product (GDP), tertiles of Gini Coefficient and the educational system. Meta-regressions will be conducted to determine if pronounced differences are present.

All analyses will be conducted using STATA 15.1 software.

Publication plan and offer of co-authorship

We plan to submit this analysis to a peer-review journal for publication with an aimed submission date of December 2018. Additionally it will be included as a chapter of Rebecca Love's PhD thesis.

Authors will be offered co-authorship on the final paper. Each cohort will be asked to nominate one or two co-authors. Adaptations will be made for cohorts with specific publication rules regarding co-authorship.

Data management

All data will be stored, managed and processed as per the data policies of the Norweign School of Sports Sciences.

A.4.3 Study level accelerometer information

Study Name*	Yrs	Months	Country	Desgn	Files*	Age (y)	Model	Epoch
ALSPAC	2003-07	All	United Kingdom	Long.	10044	10-15	7164, 71256,GT1M	60
Ballabeina Study	2008-09	June-Sept	Switzerland	Inter.	1052	4-8	GT1M	15
Belgium Pre-School Study	2006;08-09	Oct-March	Belgium	CS	433	3-7	GT1M	15
CHASE	2006-07	Jan-Feb	United Kingdom	CS	2011	9-10	GT1M	15
COSCIS	2001-05	Oct-May	Denmark	Inter.	615	6-11	7164	60
EYHS (Denmark)	1997-98; 2003-04	All	Denmark	Long.	2089	8-18	7164	60
EYHS (Estonia)	1998-99	Aug-May	Estonia	CS	669	8-17	7164	60
EYHS (Norway)	1999-00	Feb-Oct	Norway	CS	390	9-10	7164	60
EYHS (Portugal)	1999-00	Jan-July	Portugal	Long.	1358	8-18	GT1M	60
EYHS SPAIN	2008-10	-	SPAIN	CS	449	8-10	GT1M	15
GINIplus	2011-14	All	Germany	CS	1403	14-17	GT3X	60
Helena	2006-07	All	Austria, Belgium, France, Germany, Greece, Hungary, Italy, Spain, Sweden	CS	2767	13-17	GT1M	15
IDEFICS	2007-2010	Sept-May	Italy, Estonia, Cyprus, Belgium. Sweden, Germany, Hungary, Spain	Long	7136	2-9	GT1M/Actitrainer	15,60
ISCOLE	2011-13	All	Finland	CS	500	9-11	GT3X	15
KISS	2005-06	May-Nov	Switzerland	Inter.	889	6-14	7164, GT1M	60
LISA	2011-14	All	Germany	CS	412	14-16	GT3X	60
MAGIC	2006-07	Nov-May	United Kingdom	CS	562	3-17	GT1M	60
MAL-TA	2012	Jan-May	Malta	CS	859	10-11	GT3X	10
Odense Preschool	2009	May-June	Denmark	CS	204	4-5	GT1M/GT3X	10
OPUS	2011	Aug-Nov	Denmark	Long	704	8-11	GT3X (+)	60
PANCS	2005-06	All	Norway	CS	2030	9-15	7164	10
PEACH	2006-09	Sept-July	England	Long.	1232	10-13	GT1M	15
Portugal	2008-09	All	Portugal	CS	2562	10-18	GT1M	15
PRESTYLE	2009	-	Portugal	CS	567	3-6	GT1M	5
B-Proact1V	2012-13	-	United Kingdom	CS	1207	10-11	GT3X	15
SPACE	2010	Apr-June	Denmark	Inter.	1271	11-13	GT3X	30
SPEEDY	2007	Feb-July	United Kingdom	CS	2009	9-11	GT1M	5
The Belgian Environmental PA study in Youth	2008-09	Oct-May	Belgium	CS	610	13-15	GT1M	60
The Gateshead Millennium Study (GMS)	2006-07	Oct-Dec	United Kingdom	Cross	478	6-8	GT1M	15

A.4.4 Harmonization of parental education into categories of socioeconomic position

Supplementary Appendix A: Harmonization of maternal education

Variables created

Name	**Description/Coding**
PaternalEducation1	Up to and including completion of compulsory education (coded 0) Any post-compulsory education including vocational training (1) Missing (999)
PaternalEducation2	Up to and including completion of compulsory education (coded 0) Some post-compulsory education or vocational training (1) Completed undergraduate or postgraduate education (2) Missing (999)

Item selection/prioritization

- Assuming the same construct was assessed, respondent was prioritised as follows: parent self-report, partner-proxy report, child report.
- Assuming the same respondent, construct was prioritised as follows: educational institutions attended/completed, qualifications attained, years of education completed, age at completion of education.
- Where maternal education was not available, parental education data was utilized (collected as highest level/yrs achieved from either parent), followed by years/education data attained via occupational status information

Harmonization table:

Study (country)	**Source data**		**Harmonisation**		
	Variable name: N, cat, description		**Category**	**Processing**	**Summary**
B-Proact1V (UK)	Variable: p1_educ_1 9 1 No official qualification 234 2 Up to GCSEs/GCEs/ O Levels or equiv 301 3 A levels/NVQs/GNVQs or equiv 362 4 First degree/diploma/HNC/HND or equiv 143 5 Higher degree (eg. MSc, PhD) or 194 . Missing		Paternal Education 1		
			Compulsory education (0)	No official qualification Up to GCSEs/GCEs/ O Levels or equiv	243
			Any post-compulsory education (1)	A levels/NVQs/GNVQs or equiv First degree/diploma/HNC/HND or equiv Higher degree (eg. MSc, PhD) or	806
			Missing (999)	Missing	194
			Paternal Education 2		
			Compulsory education (0)	No official qualification Up to GCSEs/GCEs/ O Levels or equiv	243
			Some post-compulsory education or vocational training (1)	A levels/NVQs/GNVQs or equiv	301
			Undergraduate or postgraduate (2)	First degree/diploma/HNC/HND or equiv	505

CHASE (UK)	Variable: Education_mother 91 "AS/A level" 242 "Degree" 226 "GCSE" 1,281 "Missing" 51 "NVQ" 19 "None" 10 "Primary education" 56 "Secondary education" 95 "Vocational"
Gateshead Millennium Study (GMS) (UK)	Variable: mumqual 168 1 Degree or equivalent 79 2 A levels or equivalent 507 3 GCSEs or equivalent 195 4 NVQs or none 78 99 missing 2 .
	Variable: mother_education_level 188 1 primary and or secondary

	Higher degree (eg. MSc, PhD) or	
Missing (999)	Missing	194
Paternal Education 1		
Compulsory education (0)	"None" "Primary education" "Secondary education" "GCSE"	311
Any post-compulsory education (1)	"NVQ" "AS/A level" "Degree" "Vocational"	479
Missing (999)	"Missing"	1281
Paternal Education 2		
Compulsory education (0)	"None" "Primary education" "Secondary education" "GCSE"	311
Some post-compulsory education or vocational training (1)	"NVQ" "AS/A level" "Vocational"	237
Undergraduate or postgraduate (2)	"Degree"	242
Missing (999)	"Missing"	1281
Paternal Education 1		
Compulsory education (0)	NVQs or none GCSEs or equivalent	702
Any post-compulsory education (1)	A levels or equivalent Degree or equivalent	247
Missing (999)	missing	78
Paternal Education 2		
Compulsory education (0)	NVQs or none GCSEs or equivalent	702
Some post-compulsory education or vocational training (1)	A levels or equivalent	79
Undergraduate or postgraduate (2)	Degree or equivalent	168
Missing (999)	Missing	78
Paternal Education 1		
Compulsory education (0)	primary and or secondary	188

PANCS (Norway)	784 2 highschool 882 3 college/university 445 .	Any post-compulsory education (1)	high-school college/university	1666
		Missing (999)	. (Missing)	445
		Maternal Education 2		
		Compulsory education (0)	primary and or secondary	188
		Some post-compulsory education or vocational training (1)	High-school	784
		Undergraduate or postgraduate (2)	College-university	882
		Missing (999)	. (Missing)	445
BEPAS (Belgium)	Variable: Educ_mother 57 1 primary education 73 2 vocational secondary education 47 3 technical secondary education 64 4 general secondary education 115 5 university education 195 6 higher non-university education 55 .	Paternal Education 1		
		Compulsory education (0)	1 primary education 2 vocational secondary education 3 technical secondary education 4 general secondary education	241
		Any post-compulsory education (1)	5 university education 6 higher non-university education	310
		Missing (999)	. (missing)	55
		Paternal Education 2		
		Compulsory education (0)	1 primary education 2 vocational secondary education 3 technical secondary education 4 general secondary education	241
		Some post-compulsory education or vocational training (1)	6 higher non-university education	115
		Undergraduate or postgraduate (2)	5 university education	195
		Missing (999)	. (missing)	55
HELENA (Multiple country sites)	Variable: Mat_Edu 213 -9 (Missing) 281 1 Lower education 878 2 Lower secondary education 1,039 3 Higher secondary education (note: according to document begins at the end of compulsory education) 1,117 4 Higher education or university degree	Paternal Education 1		
		Compulsory education (0)	1 Lower education 2 Lower secondary education	1159
		Any post-compulsory education (1)	3 Higher secondary education 4 Higher education or university degree	2156
		Missing (999)	-9	213
		Paternal Education 2		
		Compulsory education (0)	1 Lower education 2 Lower secondary education	1159
		Some post-compulsory education or vocational training (1)	3 Higher secondary education	1039
		Undergraduate or postgraduate (2)	4 Higher education or university degree	1117
		Missing (999)	-9	213
MALTA	Variable: MOTHEREDUCATION	Paternal Education 1		

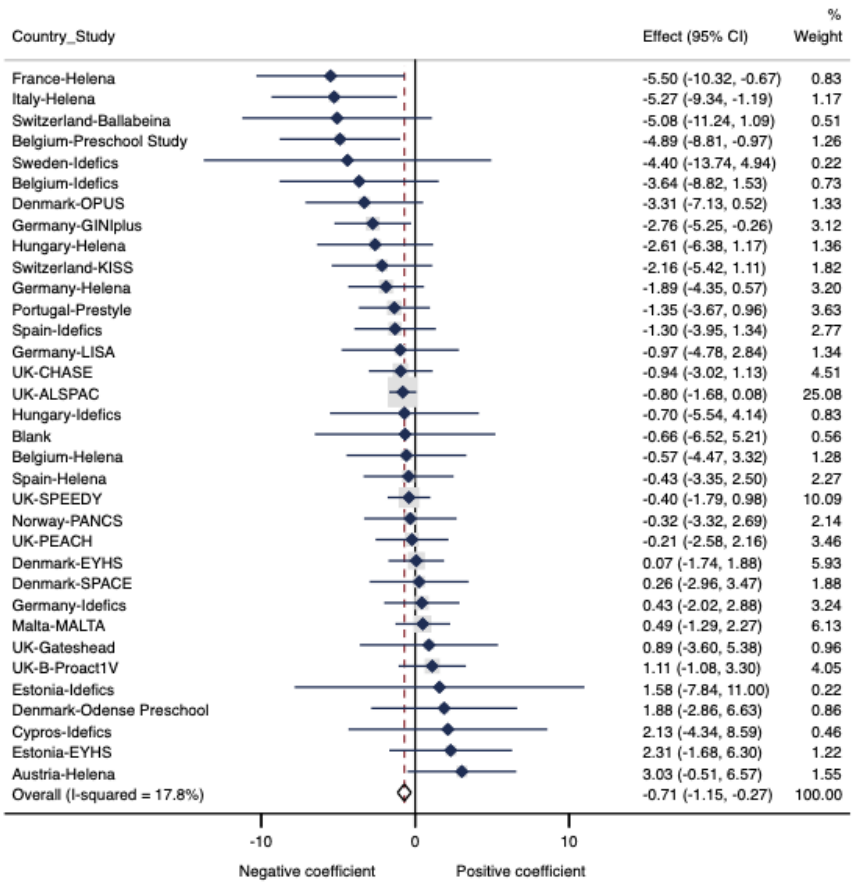
(MALTA)	19 1 Up to primary 465 2 Up to secondary 218 3 Up to Post Secondary/6th form 117 4 First degree 31 5 Higher degree (MSc, PhD) 24 .	Compulsory education (0)	1 Up to primary 2 Up to secondary	484
		Any post-compulsory education (1)	3 Up to Post Secondary/6th form 4 First degree 5 Higher degree (MSc, PhD)	366
		Missing (999)	. (Missing)	24
		Paternal Education 2		
		Compulsory education (0)	1 Up to primary 2 Up to secondary	484
		Some post-compulsory education or vocational training (1)	3 Up to Post Secondary/6th form	218
		Undergraduate or postgraduate (2)	4 First degree 5 Higher degree (MSc, PhD)	148
		Missing (999)	. (Missing)	24
OPUS (Denmark)	Variable: Highest education in household 51 1 Lower secondary (≤10 years) 288 2 Vocational (12 years) 82 3 Short higher (14 years) 233 4 Medium higher (15–16 years) 171 5 Long higher (≥17 years) 9 .	Paternal Education 1		
		Compulsory education (0)	1 Lower secondary (≤10 years)	51
		Any post-compulsory education (1)	2 Vocational (12 years) 3 Short higher (14 years) 4 Medium higher (15–16 years) 5 Long higher (≥17 years)	774
		Missing (999)	. (Missing)	9
		Paternal Education 2		
		Compulsory education (0)	1 Lower secondary (≤10 years)	51
		Some post-compulsory education or vocational training (1)	2 Vocational (12 years) 3 Short higher (14 years)	370
		Undergraduate or postgraduate (2)	4 Medium higher (15–16 years) 5 Long higher (≥17 years)	404
		Missing (999)	. (Missing)	9
SPACE (Denmark)	Variable: maternaleducation 30 1 4+ University education 276 2 3-4 years theoretical training - uni or other 81 3 1.5-2.5 years theoretical -- training/basic white collar jobs 245 4 tradesman/manual work/1 year uni 109 5 Jobs requiring limited/no training All amalgamated into one missing (.) category based on author note	Paternal Education 1		
		Compulsory education (0)	5	109
		Any post-compulsory education (1)	1 2 3 4	632
		Missing (999)	.	607
		Paternal Education 2		
		Compulsory education (0)	5	109

	188 6 Missing 156 7 unemployed 4 8 Missing 259 .	Some post-compulsory education or vocational training (1)	4 3	326
		Undergraduate or postgraduate (2)	1 2	306
		Missing (999)	.	607
Odense Preschool Project (Denmark)	Variable: Maternal_education 69 0 Up to and including completion of compulsory education 199 1 Some post-compulsory education or vocational training 182 2 Completed undergraduate or postgraduate education * Author pre-harmonized data *	Paternal Education 1		
		Compulsory education (0)	0	69
		Any post-compulsory education (1)	1 2	381
		Missing (999)	.	0
		Paternal Education 2		
		Compulsory education (0)	0	69
		Some post-compulsory education or vocational training (1)	1	199
		Undergraduate or postgraduate (2)	2	182
		Missing (999)	.	0
IDEFICS	The education level of parents was attained by a questionnaire utilizing the International Standard Classification of Education (highest education level of parents either the mother or father was considered). Three levels of education (low, medium, high) were created out of the six ISCED levels of the parental questionnaire: International Standard Classification of Education According to standards the three levels created by IDEFICS above correspond to: - Low: (0, 1, 2): Early childhood education, primary education, lower secondary education - Medium (3, 4): Upper secondary education, post-secondary non-tertiary education - High (5, 6): Short cycle tertiary education, Bachelors or equivalent	Paternal Education 1		
		Compulsory education (0)	Low	568
		Any post-compulsory education (1)	Middle, High	8206
		Missing (999)	.	234
		Paternal Education 2		
		Compulsory education (0)	Low	568
		Some post-compulsory education or vocational training (1)	Middle	4122
		Undergraduate or postgraduate (2)	High	4084
		Missing (999)	.	234
	Harmonized by author based on country context into the Maternal Education 2 categories.	Paternal Education 1		
		Compulsory education (0)	0	39

LISA (Germany)	39 0 Up to and including completion of compulsory education 124 1 Some post-compulsory education or vocational training 270 2 Completed undergraduate or postgraduate education 2 999 Missing		Any post-compulsory education (1)	1 2	394
			Missing (999)	999	2
			Paternal Education 2		
			Compulsory education (0)	0	39
			Some post-compulsory education or vocational training (1)	1	124
			Undergraduate or postgraduate (2)	2	270
			Missing (999)	999	2
GINIplus (Germany)	Harmonized by author based on country context into the Maternal Education 2 categories. 109 0 Up to and including completion of compulsory education 470 1 Some post-compulsory education or vocational training 595 2 Completed undergraduate or postgraduate education 73 999 Missing		Paternal Education 1		
			Compulsory education (0)	0	109
			Any post-compulsory education (1)	1 2	1065
			Missing (999)	999	73
			Paternal Education 2		
			Compulsory education (0)	0	109
			Some post-compulsory education or vocational training (1)	1	470
			Undergraduate or postgraduate (2)	2	595
			Missing (999)	999	73
Prestyle Portugal	Prestyle Low - until 9th grade - 9 years of study Middle - until 12th year - 12 years of study High - bachelor or graduate 265 0 Low 114 1 Medium 73 2 High 126 . Missing		Paternal Education 1		
			Compulsory education (0)	0	265
			Any post-compulsory education (1)	1 & 2	187
			Missing (999)	.	126
			Paternal Education 2		
			Compulsory education (0)	0	265
			Some post-compulsory education or vocational training (1)	1	114
			Undergraduate or postgraduate (2)	2	73
			Missing (999)	.	126

A.4.5 Additional models

Figure 1: Multivariate meta-analysis of individual participant data (N: 26, 915) by study: Multivariable linear regressions of MPA (mins/day) by three levels of SEP 1) Low vs Middle SEP 2) Low vs High, adjusted for VPA, daily accelerometer wear time, age and sex



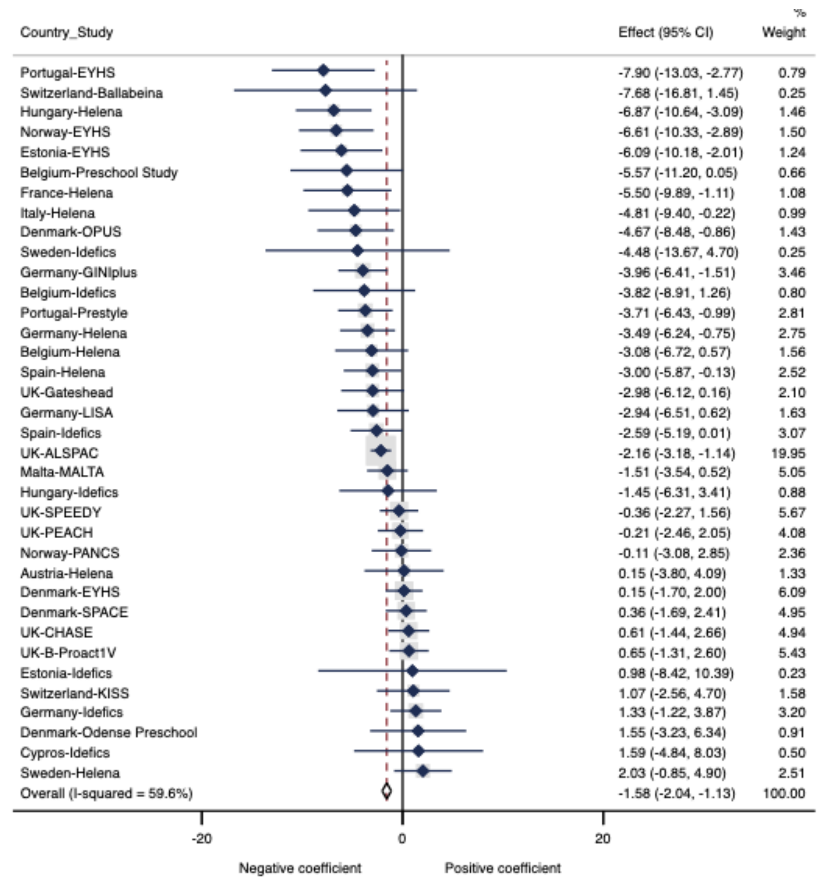
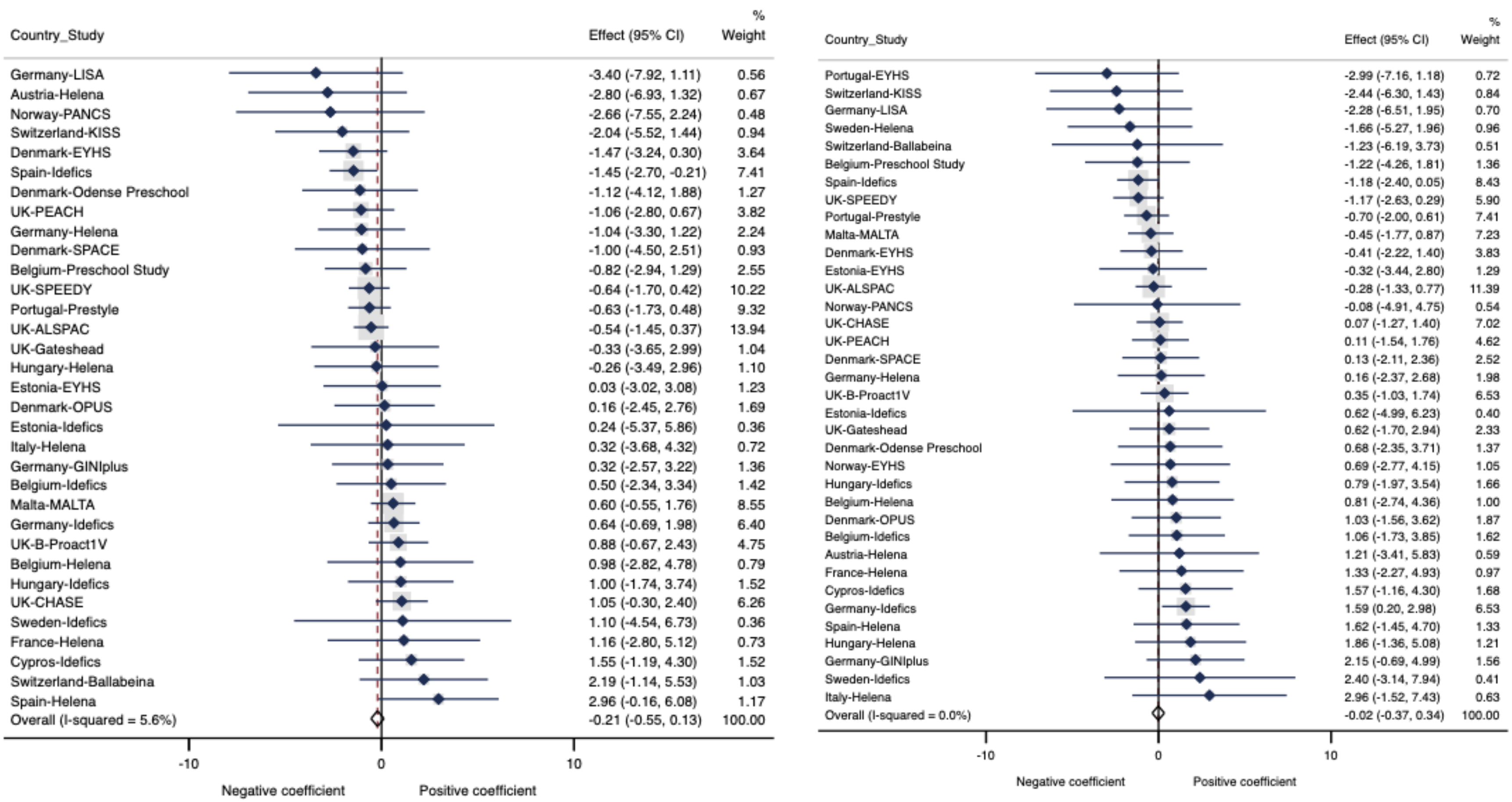


Figure 2: Multivariate meta-analysis of individual participant data (N: 25,242) by study: Multivariable linear regressions of VPA (mins/day) [unadjusted for MPA] by three levels of SEP 1) Low vs Middle SEP 2) Low vs High, adjusted for daily accelerometer wear time, age and sex



A.4.6 Participant Characteristics by Study

Table 1. Age, Gender, BMI z-score and BMI categories by Study

Country-Study	N-Total	Age		Gender (%)		BMI z-score		BMI categories (%)				Socioeconomic position (%)		
		Mean	SD	Male	Female	mean	SD	Underweight	Normal weight	Overweight	Obese	Low SEP	Middle SEP	High SEP
Austria-Helena	178	14.97	1.21	44.38	55.62	0.31	0.96	5.06	76.40	15.17	3.37	32.58	40.45	26.97
Belgium-Helena	288	14.83	1.24	45.49	54.51	-0.07	0.94	10.42	79.51	7.99	2.08	11.11	28.82	60.07
Belgium-Idefics	517	6.02	1.48	46.81	53.19	0.03	0.99	13.93	78.34	5.22	2.51	3.29	35.01	61.70
Belgium-Preschool Study	132	5.38	0.34	38.64	61.36	-0.02	1.16	14.29	72.32	12.50	0.89	43.18	43.18	13.64
Cypros-Idefics	433	6.24	1.17	48.73	51.27	0.44	1.35	13.16	64.43	14.32	8.08	2.77	45.50	51.73
Denmark-EYHS	1442	12.20	2.93	43.97	56.03	0.20	1.03	7.91	77.32	12.69	2.08	20.60	41.96	37.45
Denmark-Odense Preschool	401	5.84	0.29	49.88	50.12	0.17	0.82	6.14	85.17	7.42	1.28	13.72	45.14	41.15
Denmark-OPUS	693	9.98	0.63	52.09	47.91	0.15	1.08	11.50	75.84	11.35	1.31	6.20	44.59	49.21
Denmark-SPACE	699	12.40	0.62	51.36	48.64	0.06	1.09	9.73	76.55	11.95	1.77	47.64	11.02	41.34
Estonia-EYHS	581	12.29	3.00	44.06	55.94	-0.03	0.97	10.84	79.35	8.95	0.86	29.43	36.83	33.73
Estonia-Idefics	1095	5.90	1.97	48.49	51.51	0.28	1.08	10.05	76.35	9.95	3.65	0.55	43.29	56.16
France-Helena	187	14.33	0.97	40.11	59.89	0.14	1.06	8.56	74.87	12.83	3.74	20.32	28.34	51.34
Germany-GINIplus	1117	15.70	0.55	45.39	54.61	0.00	1.01	10.66	75.77	11.66	1.91	8.95	40.11	50.94
Germany-Helena	528	14.38	1.24	50.19	49.81	0.58	1.13	5.11	67.23	18.56	9.09	41.86	34.28	23.86
Germany-Idefics	1043	6.33	1.77	50.05	49.95	0.36	1.09	8.15	75.36	11.70	4.79	11.79	51.77	36.43
Germany-LISA	418	15.30	0.27	51.67	48.33	0.00	0.99	8.46	79.10	10.70	1.74	9.09	28.71	62.20
Hungary-Helena	264	14.75	1.12	43.18	56.82	0.23	1.05	5.68	74.62	15.15	4.55	37.50	31.82	30.68
Hungary-Idefics	1416	6.55	1.67	50.28	49.72	0.22	1.25	15.04	68.15	11.37	5.44	1.91	53.32	44.77
Italy-Helena	172	14.57	1.07	39.53	60.47	0.45	1.12	6.98	64.53	23.26	5.23	26.74	45.93	27.33
Malta-MALTA	775	10.72	0.34	50.97	49.03	0.77	1.33	7.10	59.87	22.06	10.97	55.87	26.06	18.06
Norway-EYHS	344	9.68	0.33	50.00	50.00	0.18	0.97	6.14	81.58	11.40	0.88	46.22	0.00	53.78
Norway-PANCS	1469	11.57	2.83	50.99	49.01	0.24	1.05	7.47	77.04	12.27	3.22	9.12	41.80	49.08
Portugal-EYHS	603	11.74	2.82	51.41	48.59	0.47	1.17	5.65	71.76	16.45	6.15	94.53	0.00	5.47
Portugal-Prestyle	419	4.67	0.82	39.86	60.14	1.05	1.08	2.63	63.25	24.58	9.55	58.71	24.82	16.47
Spain-Helena	348	14.70	1.20	50.86	49.14	0.37	1.04	5.46	72.41	18.68	3.45	40.80	28.74	30.46
Spain-Idefics	1234	5.72	1.77	51.54	48.46	0.56	1.10	7.29	71.56	15.32	5.83	6.97	40.60	52.43
Sweden-Helena	183	14.84	1.18	38.25	61.75	0.04	1.01	7.10	79.78	10.93	2.19	38.25	0.00	61.75
Sweden-Idefics	588	6.24	1.96	51.19	48.81	0.15	1.00	10.54	79.93	8.33	1.19	1.36	25.00	73.64
Switzerland-Ballabeina	126	5.92	0.55	44.54	55.46	0.20	1.09	10.92	74.79	12.61	1.68	25.40	62.70	11.90
Switzerland-KISS	390	9.31	2.12	48.97	51.03	0.21	1.07	9.45	76.12	11.81	2.62	20.26	51.79	27.95
UK-ALSPAC	4668	11.81	0.23	47.31	52.69	0.31	1.16	8.53	70.93	16.84	3.70	22.75	52.51	24.74
UK-B-Proact1V	927	6.00	0.42	52.43	47.57	0.37	0.92	4.41	83.14	10.07	2.38	22.44	27.62	49.95
UK-CHASE	673	9.94	0.40	50.37	49.63	0.70	1.28	6.55	61.46	22.62	9.38	40.42	29.27	30.31
UK-Gateshead	428	7.44	0.45	51.40	48.60	0.48	1.08	5.65	74.59	15.76	4.00	67.06	9.58	23.36
UK-PEACH	589	10.92	0.44	48.56	51.44	0.30	1.15	10.54	70.07	15.82	3.57	46.86	24.45	28.69
UK-SPEEDY	1547	10.25	0.31	44.60	55.40	0.45	1.16	6.56	70.39	18.05	5.00	40.72	43.89	15.38

Table 2. Characteristics: Moderate physical activity (mins/day), vigorous physical activity (mins/day) and daily accelerometer wear time (mins/day) by Study

Country-Study	**N-total**	**VPA (mins/day)**		**MPA (mins/day)**		**Accelerometer wear time (mins/day)**	
		Mean	SD	Mean	SD	Mean	SD
Austria-Helena	178	31.72	12.08	15.29	13.02	782.20	85.30
Belgium-Helena	288	25.41	11.68	12.73	10.50	815.56	75.51
Belgium-Idefics	517	29.05	15.94	6.14	6.25	633.11	184.19
Belgium-Preschool Study	132	38.52	14.88	8.40	5.75	704.44	49.66
Cypros-Idefics	433	26.24	16.22	5.19	4.90	736.65	240.48
Denmark-EYHS	1442	31.21	19.74	13.59	13.53	787.25	66.86
Denmark-Odense Preschool	401	43.15	18.29	16.70	9.99	747.61	53.16
Denmark-OPUS	693	37.55	16.79	11.52	8.36	1035.07	50.64
Denmark-SPACE	699	35.27	15.72	18.74	14.64	805.86	56.76
Estonia-EYHS	581	43.37	26.08	18.07	16.01	801.37	60.47
Estonia-Idefics	1095	24.55	20.07	6.24	8.23	522.82	308.84
France-Helena	187	28.77	12.80	11.55	10.02	788.02	82.52
Germany-GINIplus	1117	28.39	15.01	15.20	13.37	1054.11	71.78
Germany-Helena	528	29.89	15.64	13.29	13.11	808.38	104.95
Germany-Idefics	1043	30.16	18.90	6.86	7.34	552.33	188.73
Germany-LISA	418	30.38	13.67	15.98	12.53	1055.24	66.03
Hungary-Helena	264	30.22	14.74	14.93	11.66	728.04	86.12
Hungary-Idefics	1416	29.73	16.82	7.20	7.40	694.04	188.81
Italy-Helena	172	27.25	13.27	10.56	11.86	803.04	81.62
Malta-MALTA	775	30.45	15.79	7.74	7.13	823.39	85.78
Norway-EYHS	344	46.44	23.26	22.42	16.82	786.81	55.15
Norway-PANCS	1469	41.12	19.29	21.87	26.77	796.05	71.53
Portugal-EYHS	603	37.98	22.90	12.97	12.59	786.91	68.96
Portugal-Prestyle	419	32.89	15.46	5.50	4.95	740.54	95.47
Spain-Helena	348	29.54	13.85	14.90	13.06	803.01	66.91
Spain-Idefics	1234	32.43	18.14	6.13	5.78	672.69	157.11
Sweden-Helena	183	27.34	10.69	14.73	12.34	771.89	82.07
Sweden-Idefics	588	30.93	18.87	7.75	8.40	595.36	215.15
Switzerland-Ballabeina	126	46.34	18.82	11.67	8.13	716.84	60.71
Switzerland-KISS	390	51.99	17.66	21.59	14.52	916.33	113.07
UK-ALSPAC	4668	39.31	16.60	16.43	12.70	773.20	58.81
UK-B-Proact1V	927	41.00	15.70	11.47	8.55	680.00	63.12
UK-CHASE	673	34.34	16.42	8.00	7.64	778.72	78.50
UK-Gateshead	428	43.04	17.27	12.20	10.23	716.85	58.29
UK-PEACH	589	36.82	15.98	10.87	8.82	745.35	69.39
UK-SPEEDY	1547	36.76	16.39	12.09	9.92	736.98	62.21

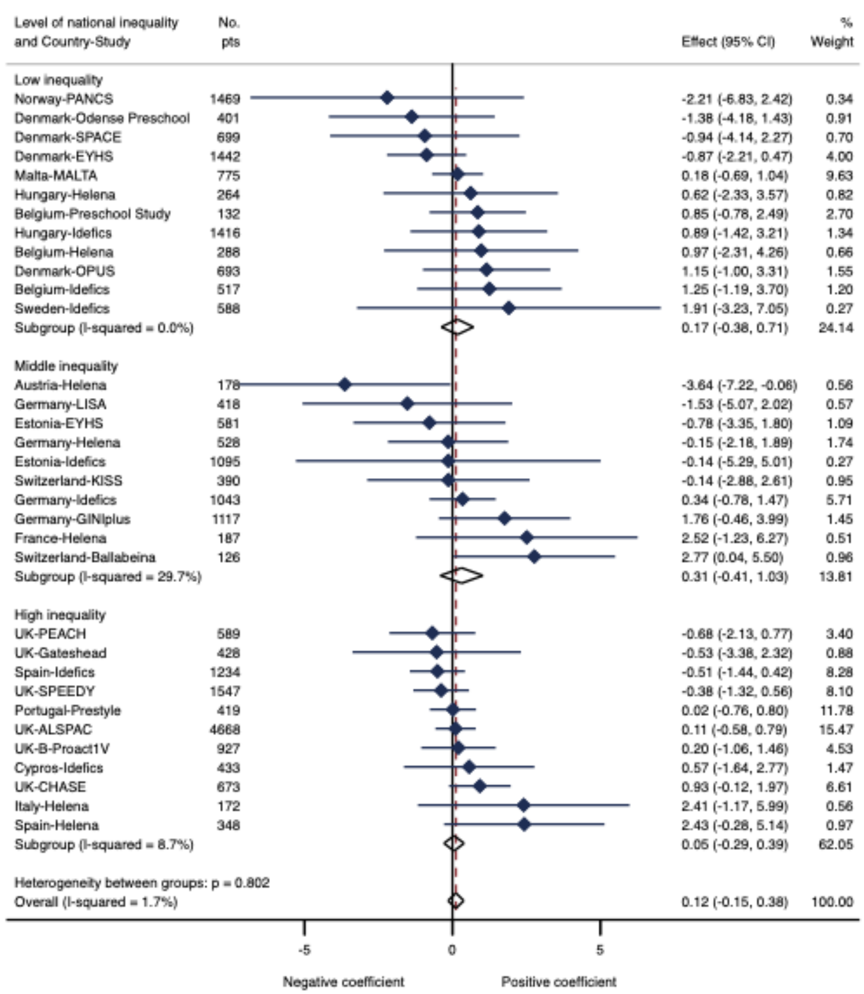
A.4.7 Physical activity characteristics by level of socioeconomic position

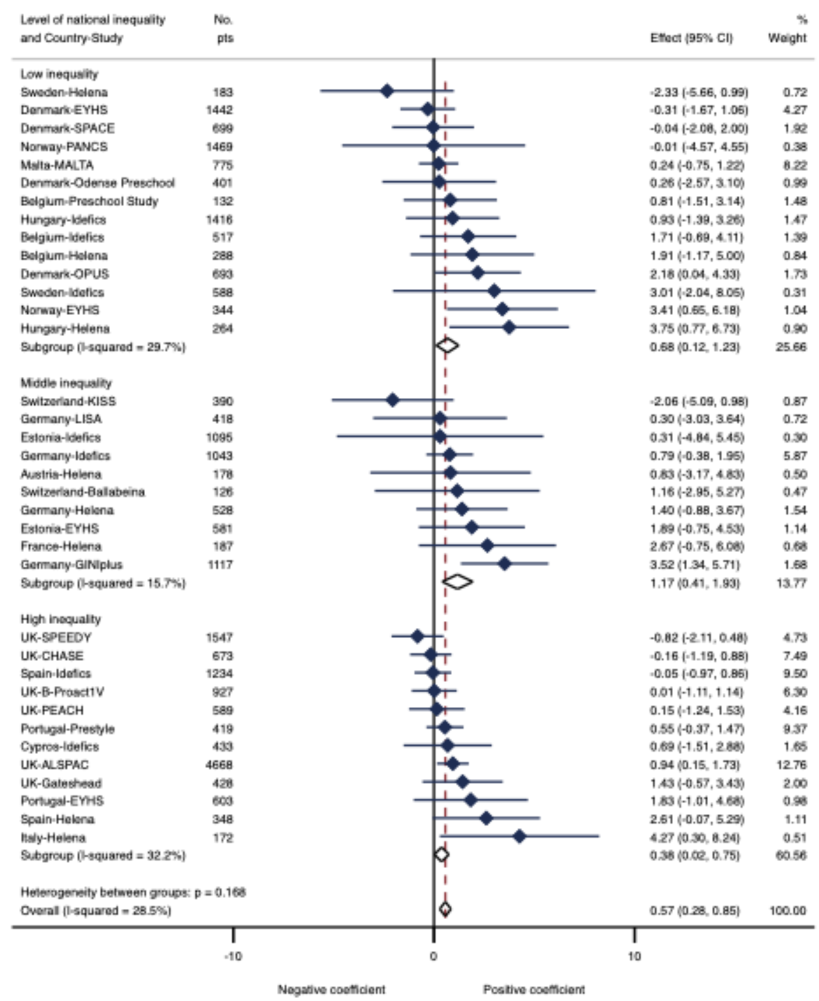
	Low SEP			Middle SEP			High SEP	
	N	Mean		N	Mean		N	Mean
VPA	6188	13.67		7632	14.52		6769	15.56
	279	6.29		2795	6.44		3252	6.76
		13.35			12.35			12.70
	Low SEP			Middle SEP			High SEP	
	N	Mean		N	Mean		N	Mean
MPA	6188	37.1		7632	36.9		6769	35.9
	279	30.9		2795	29.2		3252	29.1
		36.83			34.84			33.69
	Low SEP			Middle SEP			High SEP	
	N	Mean		N	Mean		N	Mean
Accelerometer wear time	6188	777.85		7632	805.62		6769	825.9
	279	608.91		2795	625.31		3252	627.35
		770.56			757.29			761.47

Average daily minutes/day	Low SEP (N: 6, 467)	Medium SEP (N: 10, 427)	High SEP (N: 10, 021)
Vigorous physical activity (VPA)	13.35	12.35	12.70
Moderate physical activity (MPA)	36.8	34.84	33.69
Accelerometer wear time	770.56	757.29	761.27

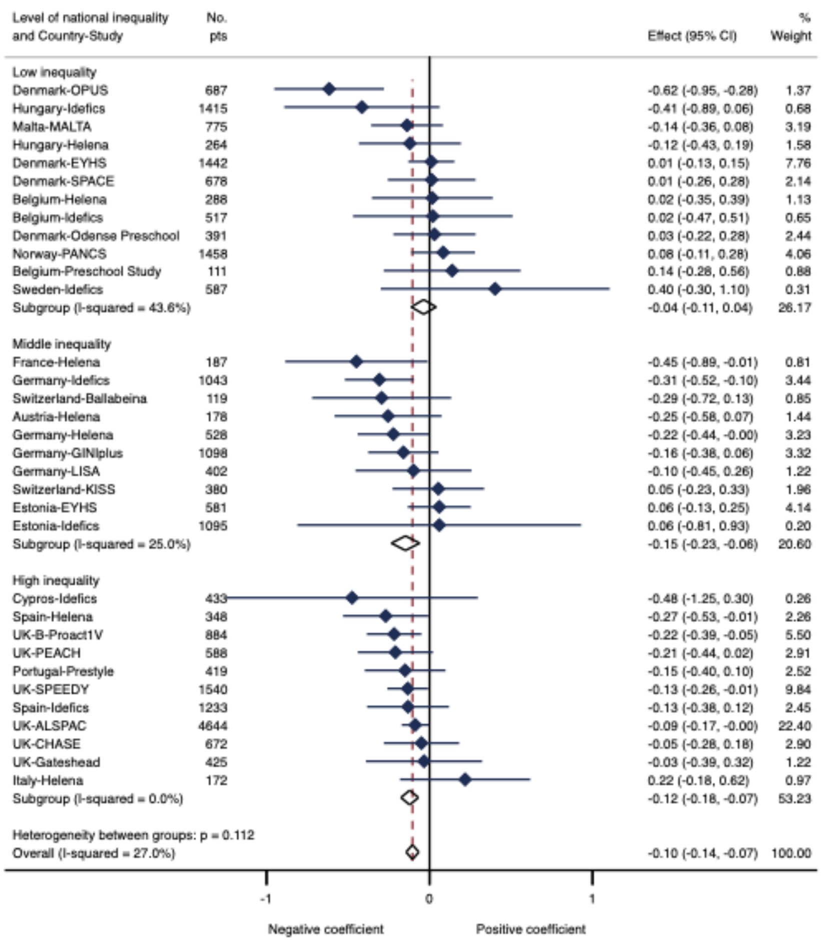
A.4.8 Subgroup meta-analyses – by low, middle and high national level inequality

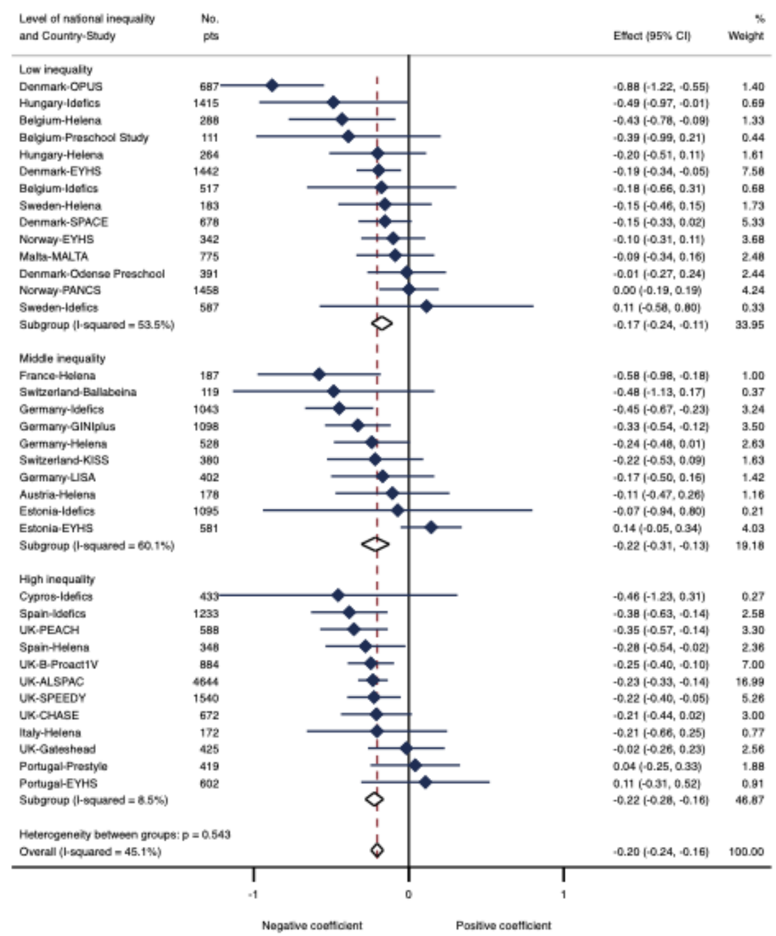
4.8.1: Multivariate subgroup meta-analyses by low, middle and high national level inequality (Via Gini coefficient) of individual participant data (N: 26, 915). Multivariable linear regressions of VPA (mins/day) by three levels SEP 1) Low vs Middle SEP 2) Low vs High, adjusted for MPA, daily accelerometer wear time, age and sex.



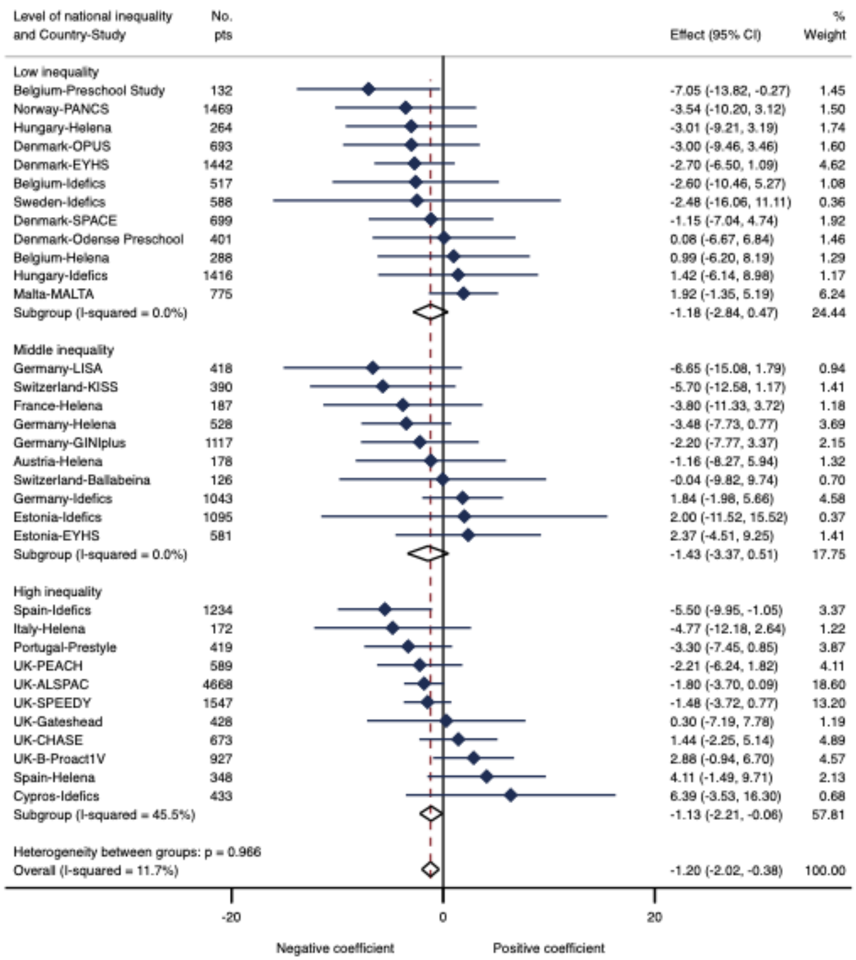


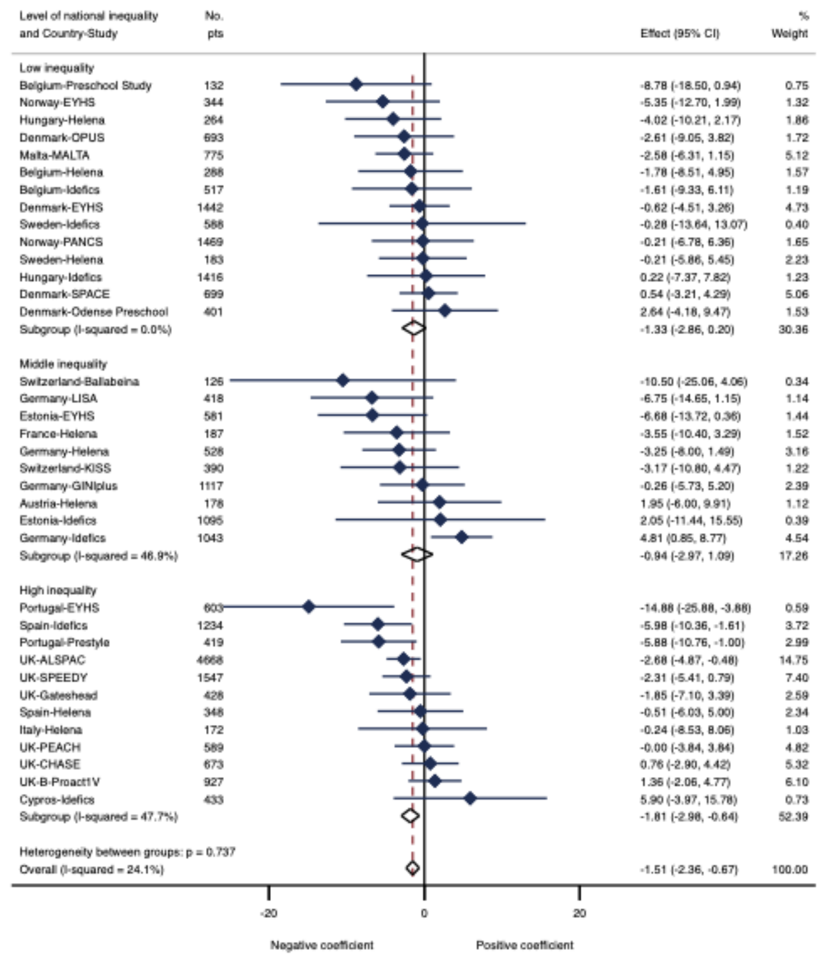
4.8.2: Multivariate subgroup meta-analyses by low, middle and high national level inequality (Via Gini coefficient) of individual participant data (N: 26, 915). Multivariable linear regressions of bmi z-score by three levels SEP 1) Low vs Middle SEP 2) Low vs High, adjusted for age and sex





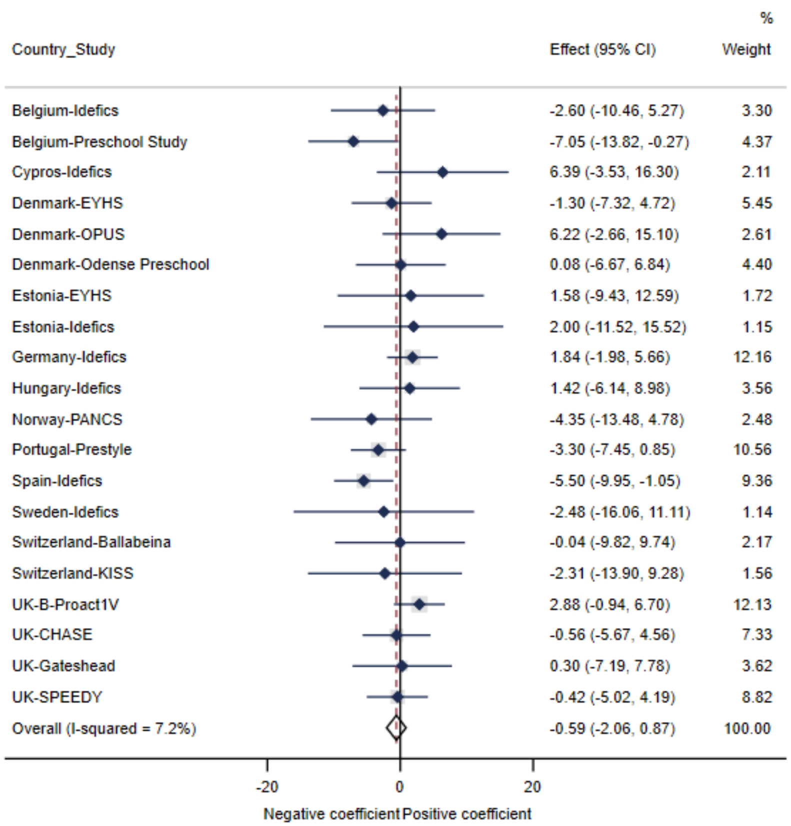
4.8.3: Multivariate subgroup meta-analyses by low, middle and high national level inequality (Via GINI coefficient) of individual participant data (N: 26, 915). Multivariable linear regressions of MVPA (mins/day) by three levels of SEP, 1) Low vs Middle SEP 2) Low vs High, adjusted for age and sex

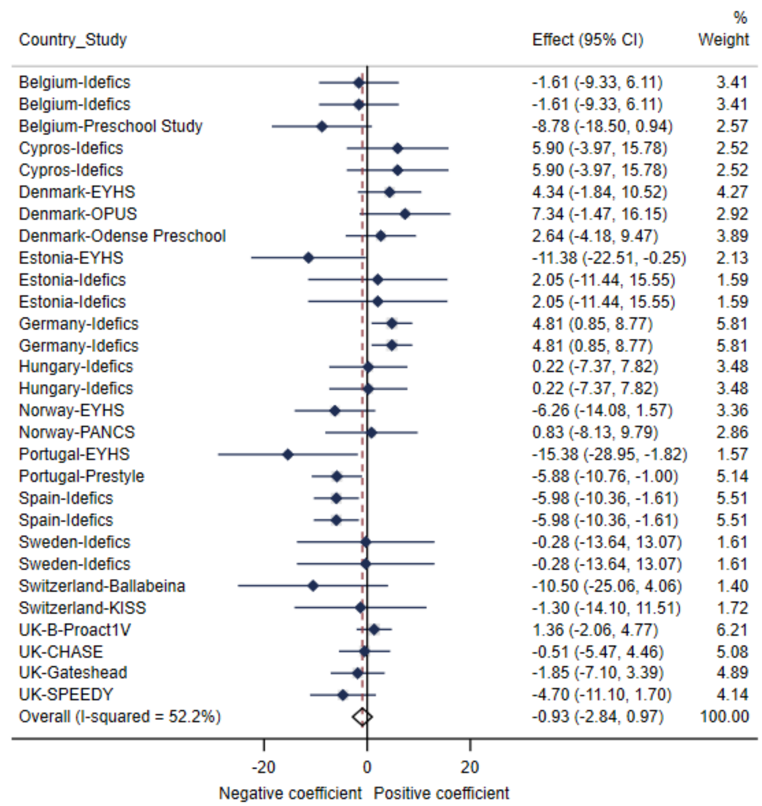




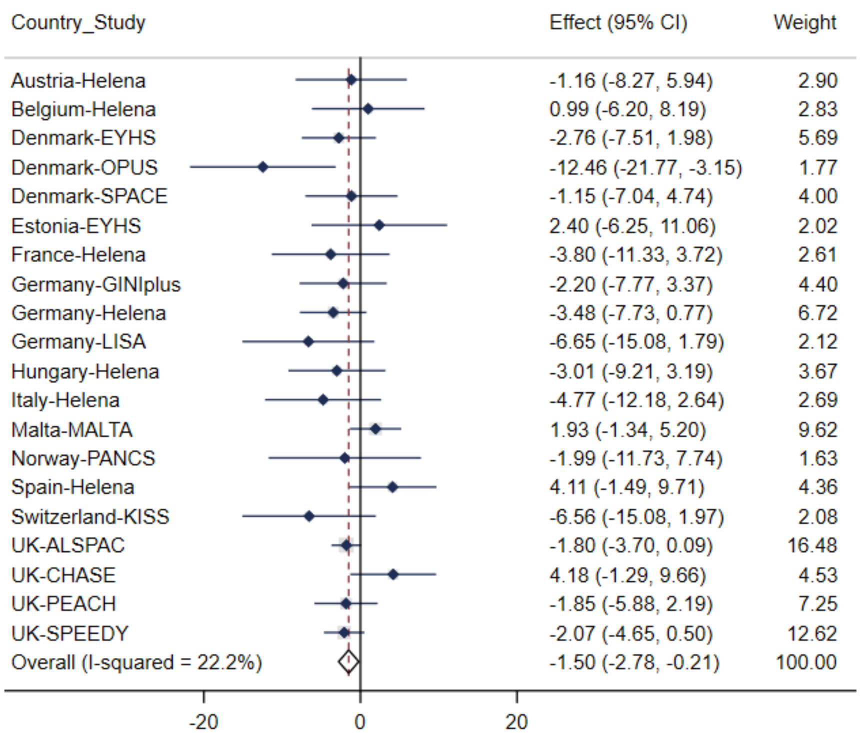
A.4.9 Subgroup meta-analyses – by age (below and above 10 years of age)

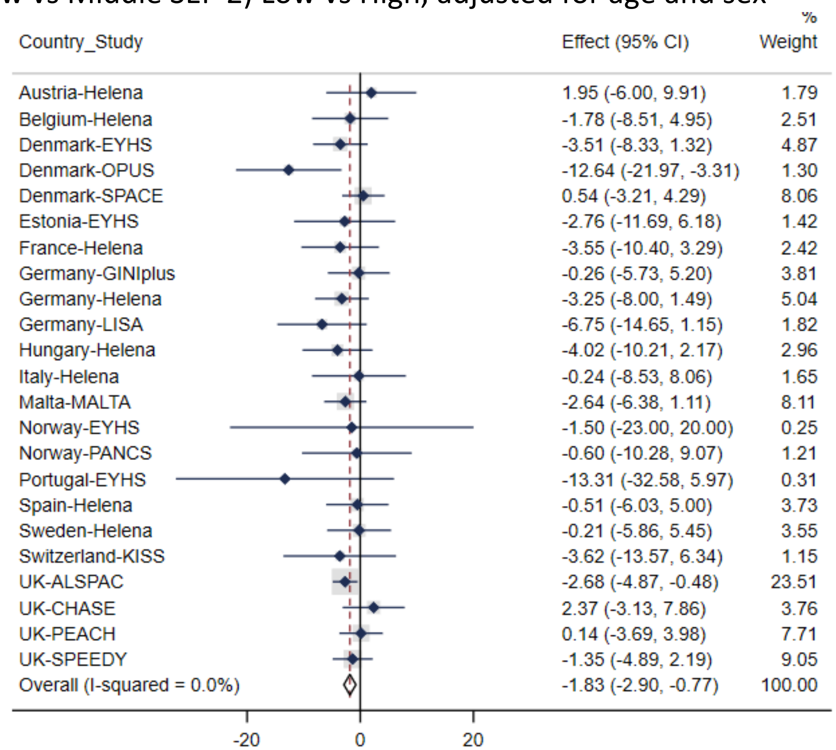
4.9.1: Participants under the age of 10 multivariate subgroup meta-analyses of individual participant data (N: 26, 915). Multivariable linear regressions of **MVPA** (mins/day) by three levels of SEP, 1) Low vs Middle SEP 2) Low vs High, adjusted for age and sex



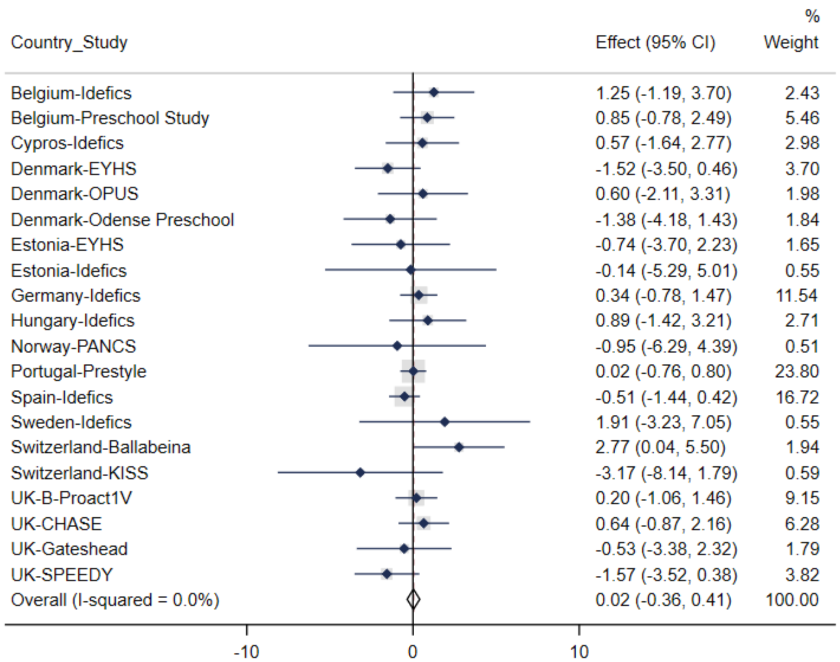


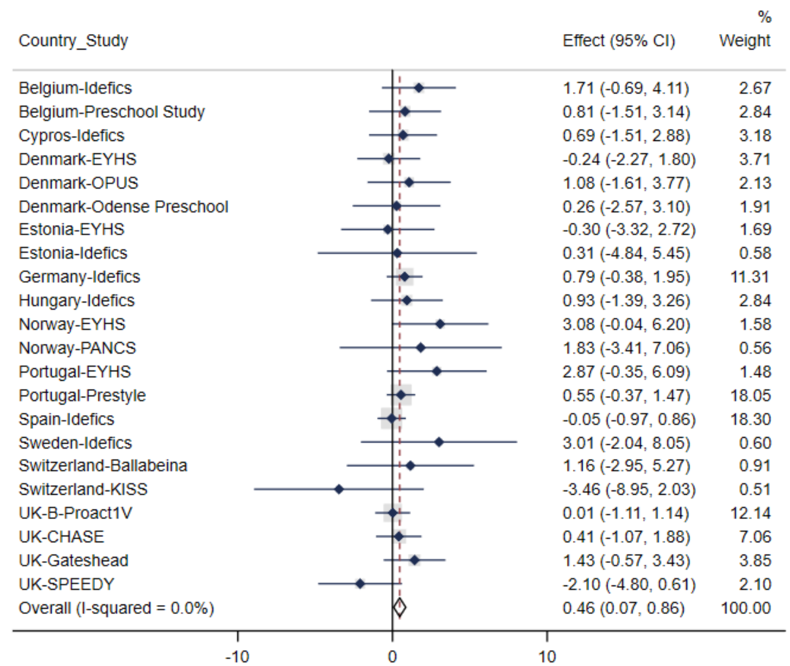
4.9.2: Participants above the age of 10 multivariate subgroup meta-analyses of individual participant data (N: 26, 915). Multivariable linear regressions of **MVPA** (mins/day) by three levels of SEP, 1) Low vs Middle SEP 2) Low vs High, adjusted for age and sex



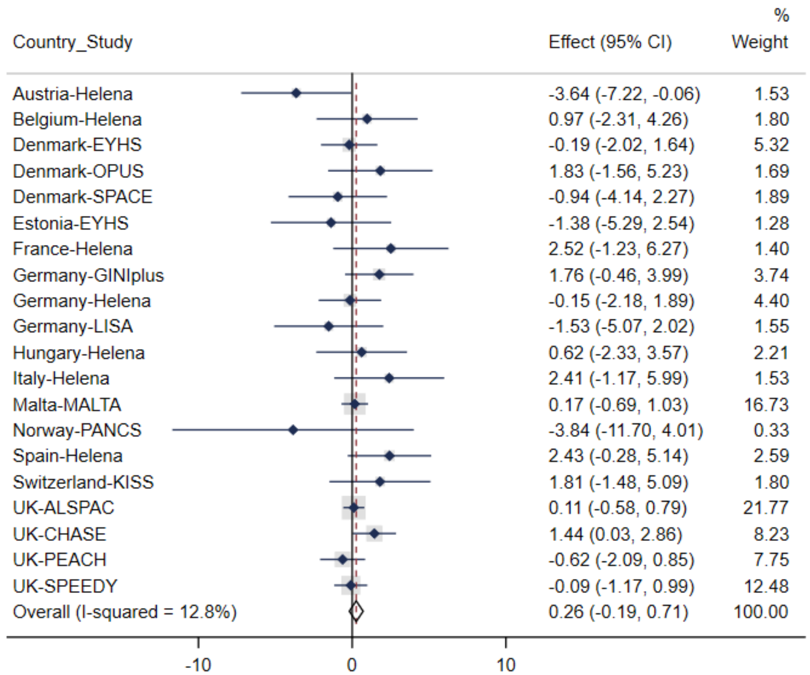


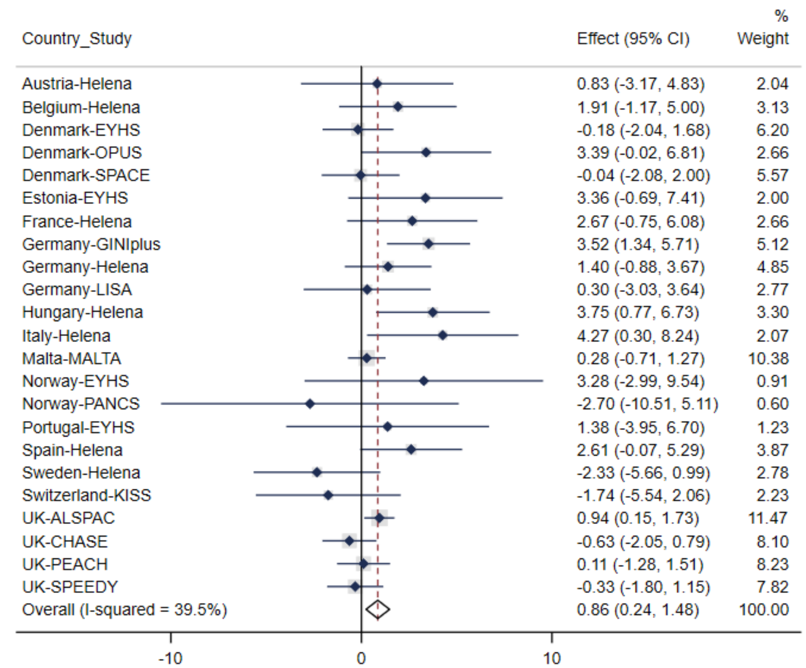
4.9.3: Participants under the age of 10 multivariate subgroup meta-analyses of individual participant data (N: 26, 915). Multivariable linear regressions of **VPA** (mins/day) by three levels of SEP, 1) Low vs Middle SEP 2) Low vs High, adjusted for age and sex



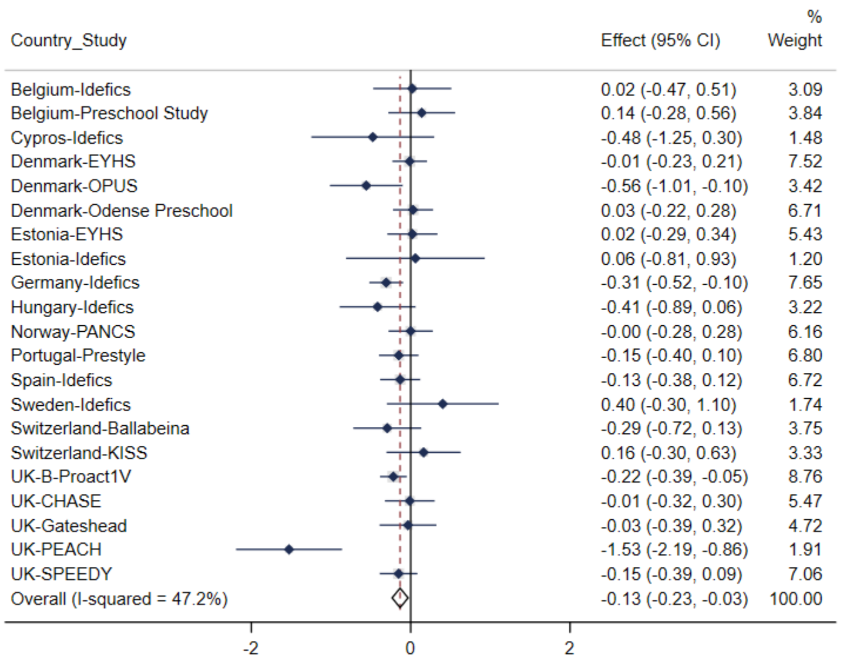


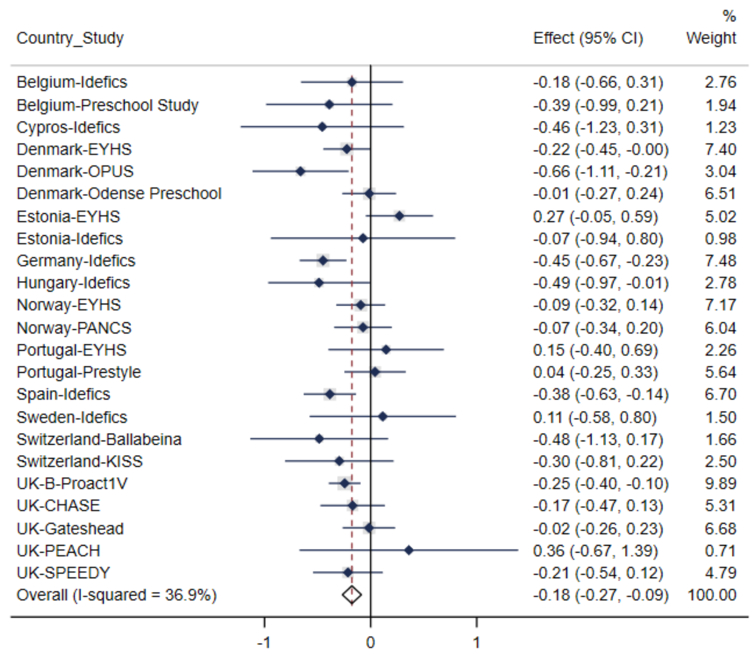
4.9.4: Participants over the age of 10 multivariate subgroup meta-analyses of individual participant data (N: 26, 915). Multivariable linear regressions of **VPA** (mins/day) by three levels of SEP, 1) Low vs Middle SEP 2) Low vs High, adjusted for age and sex



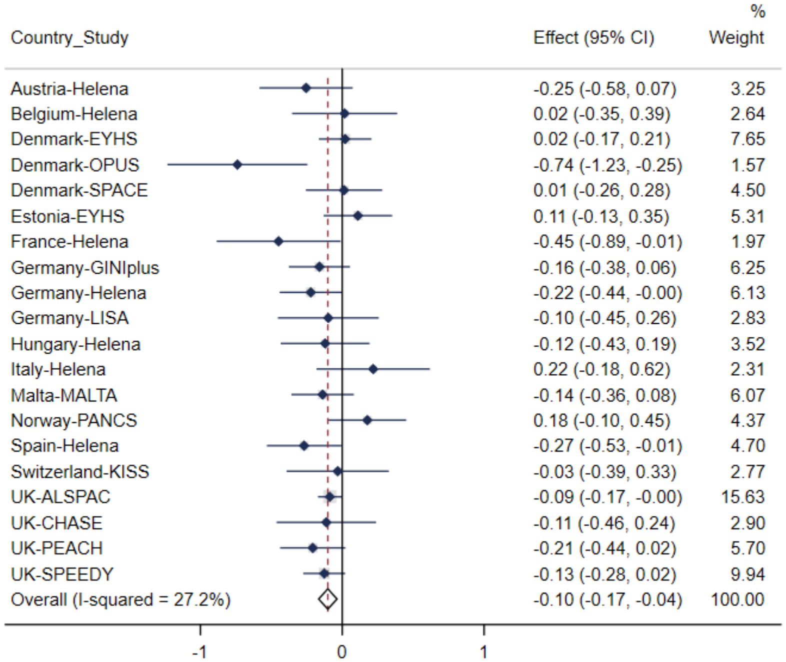


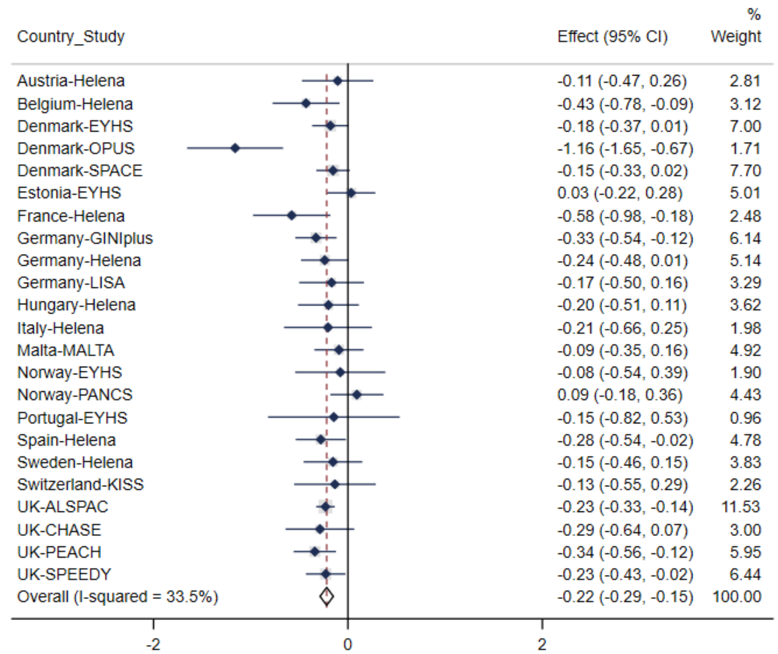
4.9.5: Participants under the age of 10 multivariate subgroup meta-analyses of individual participant data (N: 26, 915). Multivariable linear regressions of **bmi z-score** by three levels of SEP, 1) Low vs Middle SEP 2) Low vs High, adjusted for age and sex





4.9.6: Participants over the age of 10 multivariate subgroup meta-analyses of individual participant data (N: 26, 915). Multivariable linear regressions of **bmi z-score** by three levels of SEP, 1) Low vs Middle SEP 2) Low vs High, adjusted for age and sex





APPENDIX 5: CHAPTER 5

A.5.1 PROSPERO Registration

PROSPERO
International prospective register of systematic reviews

National Institute for Health Research

A systematic review exploring the equity effects of children's physical activity interventions

Rebecca Love, Esther van Sluijs, Jean Adams

Citation

Rebecca Love, Esther van Sluijs, Jean Adams. A systematic review exploring the equity effects of children's physical activity interventions. PROSPERO 2016 CRD42016034020 Available from: http://www.crd.york.ac.uk/PROSPERO/display_record.php?ID=CRD42016034020

Review question

What effect do children's physical activity interventions have on inequalities in physical activity behaviour as outlined by the PROGRESS-Plus framework (place of residence, race/ethnicity/ culture/language, occupation, gender/sex, religion, education, SES, and social capital)?
What methods have been utilized to examine equity effects in studies examining the effectiveness of children's physical activity interventions?

Searches

Databases to be searched:
- ERIC
- EMBASE
- SCOPUS
- PsycINFO
- OVID Medline
- SPORTDiscus

Additional searches:
- Checking the reference lists of all included papers
- Searching for names of all known and relevant trials
- Carrying out citation searches of key publications to identify subsequent publications
- Scanning of existing reviews on the same topic for missing trials (Dobbins et al. 2013; Russ et al. 2014; Metcalf et al. 2012; Sims et al. 2015; Van Sluijs et al. 2007)

Restrictions:
Restricted to:
- English language journals
- Population: Children and adolescents (4-18 years of age) in school
- Studies that recruited samples who were from the general population (Children and adolescents selected on the basis of having a specific disease, special needs or defined as obese will be excluded)
- Intervention: Single or multicomponent interventions aimed at increasing children & adolescents levels of physical activity in the school, home or community environment
- Study design: Controlled or randomised controlled trials (cluster or individual) with a control or minimal intervention control group
- Outcomes: Objectively measured physical activity at baseline and follow-up through assessment in the same participants (accelerometer, heart rate, pedometer)

Types of study to be included

Included:- Controlled or randomised controlled trials (cluster or individual) with a control or minimal intervention control group.Excluded:- All qualitative trials. RCTs comparing two active intervention arms.

Condition or domain being studied

Physical activity during childhood and adolescence plays a critical role in promoting health and well-being and reducing future disease risk. Yet, most children and adolescents are not active enough to benefit their health.

Physical activity behaviour is socioeconomically graded and proposed to be a critical contributor to the development of a range of health inequities including the stark, graded differences in obesity prevalent across populations.

Participants/population

Inclusion Criteria:
- Children and adolescents (4-18 years of age) in school.
- Study populations recruited from the general population.

Exclusion Criteria:
- Pre-school populations of children.
- Children and adolescents selected on the basis of having a specific disease or special needs
- Studies where participants are defined as obese and the sample is restricted to an obese population will be excluded

Intervention(s), exposure(s)

Inclusion criteria
- At least one measure of physical activity (MVPA; Total activity; Energy expenditure), measured objectively (e.g. accelerometer, heart rate, pedometer) at baseline and follow up.

Exclusion criteria
- Studies with subjectively measured physical activity outcomes (e.g. self-report, questionnaires).
- Studies without both a pre and post measure of physical activity behaviour

Comparator(s)/control

- Interventions could have been compared with a control intervention (standard or usual care) or minimal intervention control group.
- Control conditions must have not included a physical activity component of any kind.

Context

All community, family and home based interventions will be included. No exclusions based on context will be made.

Primary outcome(s)

An overview of the scope studies of children's physical activity interventions that have collected data across the PROGRESS-Plus framework characteristics (place of residence, race/ethnicity/language, occupation, religion, SES and social capital) and analysis of equity effects/trends within each characteristic.

Secondary outcome(s)

A synthesis of the methods used to examine equity effects in studies examining the effectiveness of children's physical activity interventions.

Data extraction (selection and coding)

The initial literature search and scanning stages (title, abstract) will be conducted by one reviewer (RL). A 15% random sample will be double checked at each stage (EV). Two reviewers will independently screen full texts for inclusion and discuss any discrepancies (RL, EV, JA). Data extraction will be conducted by RL with 100% checked for consistency (EV, JA).

Risk of bias (quality) assessment

Two reviewers will independently quality assess each included study (RL, EV, JA). As recommended by Cochrane Public Health Group, the Effective Public Health Practice Project Quality Assessment Tool for Quantitative Studies, will be used to assess the methodological quality of each included study (http://www.ephpp.ca/tools.html).

Strategy for data synthesis

The results of the systematic review will be synthesized using both graphical and narrative methods, including the use of harvest plots. For trials exploring intervention effects across one or more of the

PROGRESS Plus characteristics, findings will be synthesized using Harvest Plots. Harvest Plots are a useful graphical method for synthesizing, displaying and assimilating the findings about the differential effects of population-level interventions (Olgivie et al. 2008). PROGRESS-Plus characteristics applicable to children that will be analysed will include place of residence; race/ethnicity; gender/sex; religion and socioeconomic status. A sensitivity analysis will be conducted to determine if all appropriate studies were captured in the search.
As a result of the scoping design of this review, it is not expected that the included studies will be clinically homogeneous enough to undertake a meta-analysis of the results.

Analysis of subgroups or subsets

None planned

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Anticipated or actual start date

01 December 2015

Anticipated completion date

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Conflicts of interest

None known

Language

English

Country

England

Stage of review

Review_Completed_published

Details of final report/publication(s)

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Details of any existing review of the same topic by the same authors

Stage of review at time of this submission

Stage	Started	Completed
Preliminary searches	Yes	Yes
Piloting of the study selection process	Yes	Yes
Formal screening of search results against eligibility criteria	Yes	Yes
Data extraction	Yes	Yes
Risk of bias (quality) assessment	Yes	Yes
Data analysis	Yes	Yes

Versions
04 February 2016
06 February 2018

A.5.2 Medline Search Strategy

1. (child* or children or childhood or kids or adolescen* or "young person*" or "young people" or teen* or youth* or boy* or girl* or juvenile).ti,ab. 2. exp child/ 3. exp adolescent/ 4. 2 or 3 5. (child or adolescent).ti,ab. 6. 1 or 5 7. ("physical* activ*" or "physical activity" or sport* or cycling or bicycling or bicycle* or walk* or "physical education" or "physical training" or exercis* or "energy expenditure" or danc* or "physical inactivity" or "physical fitness" or lifestyle or "active travel" or commut* or "aerobic fitness").ti,ab. 8. exp motor activity/ 9. exp sports/ 10. exp exercise/ 11. exp physical exertion/ 12. exp "physical education and training"/ 13. 8 or 9 or 10 or 11 or 12 14. (motor activity or sports or exercise or physical exertion or "physical education and training").ti,ab. 15. 7 or 14 16. ("clinical trial" or "control* trial" or controlled or randomi#ation or randomised or randomized or randomization or randomly or randomisation or rct or "randomi#ed controlled trial*" or "randomised controlled trial" or "randomized controlled trial" or "cluster randomized controlled trial" or "group-randomized controlled trial" or "randomized controlled study" or "randomised controlled study" or "random* sample" or trial* or evaluation or effect* or control* or cluster or intervention).ti,ab. 17. exp randomized controlled trial/ 18. exp clinical trial/ 19. exp randomized controlled trials as topic/ 20. exp clinical trial as topic/ 21. 17 or 18 or 19 or 20 22. (randomized controlled trial or clinical trial or randomized controlled trials as topic or clinical trial as topic).ti,ab. 23. 16 or 22 24. ("case study" or "case report" or "abstract report" or letter).ti,ab. 25. exp letter/ 26. exp historical article/ 27. exp case report/ 28. 25 or 26 or 27 29. (letter or historical article or case report).ti,ab. 30. 24 or 29 31. 23 not 30 32. (accelerometer or accelerometry or accelerometers or accelerometer-assessed or "counts per minute" or CPM or triaxial or Actigraph or Yamax or Actiheart or Omron, sensewear or caltrac or walk4life or ideea or actireg or lifecorder or tritrac or genea or stepwatch or actical or actiwatch or rt3 or activpal or actimarker or dynaport or CSA or MTI or pedometer or "heart rate" or pedometry or pedometers or uniaxial or actigraphy or undimensional or "objectively measur*" or "SenseWear Pro2 Armband" or "motion sensor data" or "activity monitor" or MVPA).ti,ab. 33. exp monitoring, ambulatory/ 34. exp actigraphy/ 35. 33 or 34 36. (monitoring, ambulatory or actigraphy).ti,ab. 37. 32 or 36 38. 6 and 15 and 31 and 37 39. 6 and 15 and 31 and 37 40. limit 39 to English Language + Year limitation: 2016 - 2017

A.5.3 Characteristics of included intervention trials

Included Intervention Trials (Author (year) is included if trial has no name)	Author & Publication Year	Country of implementation
Aburto (2011)	Aburto et al. 2011	Mexico
Andrade (2014)	Andrade et al. 2014	Ecaduor
Backlund (2011)	Backlund et al. 2011	Sweden
Baranowski (2011)	Baranowski et al. 2011	USA
Baranowski (2012) RCT	Baranowski et al. 2012	USA
The Memphis Girls' health Enrichment Multi-site Studies (GEMS) Pilot trial	Beech et al. 2003	USA
Mebane on the Move Intervention	Benjamin Neelon et al. 2015	USA
Challenge! Intervention	Black et al. 2010	USA
Sport for LIFE intervention	Breslin et al. 2012	UK
Copenhagen School Child Intervention Study	Bugge et al. 2012	Denmark
Pathways	Caballero et al. 2003 & Going et al. 2002	USA
Comprehensive school physical activity program (CSPAP)	Carson et al. 2014	USA
Chen (2010)	Chen et al. 2010	USA
Web ABC study	Chen et al. 2011	USA
The Supporting Children's Outcomes using Rewards, Exercise, and Skills intervention (SCORES) Cluster RCT	Cohen et al. 2015	Australia
Beat the Street physical activity intervention	Coombes et al. 2016	UK
The Family Project	Coppins et al. 2011	UK
Boston Active School Day policy	Cradock et al. 2014	USA
Crouter (2015)	Crouter et al. 2015	USA
D'Haese (2015)	D'Haese et al. 2015	Belgium
The nutrition and enjoyable activity for teen (NEAT) girls study	Dewar et al. 2013 & Dewar et al. 2014 & Lubans et al. 2012	Australia
Dimitriou (2011)	Dimitriou et al. 2011	Greece
Apps for IMproving FITness and Increasing Physical Activity Among Young People: The AIMFIT Pragmatic Randomized Controlled Trial	Direito et al. 2015	New Zealand
Physical Activity Across the Curriculum (PAAC)	Donnelly et al. 2008	USA
Dudley (2010)	Dudley et al. 2010	Australia
The Healthy Homework pilot study	Duncan et al. 2011	New Zealand
Fit4fun Pilot Study	Eather et al. 2013	Australia
Fit4fun group randomized controlled trial	Eather et al. 2013	Australia
It's child's play: A cluster randomised controlled trial	Engelen et al. 2013	Australia
Erwin (2011)	Erwin et al. 2011	USA
Eyre (2016)	Eyre et al. 2016	UK

FATaintPHAT	Ezendam et al. 2012	Netherlands
Children's Health, Activity and Nutrition: Get Educated! (CHANGE!) Project	Fairclough et al. 2013	UK
Finkelstein (2013)	Finkelstein et al. 2013	Singapore
Ford et al. (2012)	Ford et al. 2012	UK
SWITCH what you Do, View and Chew	Gentile et al. 2009	USA
Lifestyle triple P	Gerards et al. 2015	Netherlands
Interactive Multimedia for Promoting Physical Activity (IMPACT) in Children	Goran et al. 2005	USA
GreatFun2Run	Gorley et al. 2009 & Gorley et al. 2011	UK
Gortmaker (2012)	Gortmaker et al. 2012	USA
Graves (2010)	Graves et al. 2010	UK
HEalth in Adolescents (HEIA) study	Grydeland et al. 2013	Norway
The Rope Skipping 'STAR' Programme	Ha et al. 2015	Hong Kong
Haerens (2007)	Haerens et al. 2006 & Haerens et al. 2007	Belgium
Hands (2011)	Hands et al. 2011	Australia
Harder-lauridsen (2014)	Harder-lauridsen et al. 2014	Denmark
Fit 'n' fun dudes program (2009)	Hardman et al. 2009	UK
Fit 'n' fun dudes program (2011)	Hardman et al. 2011	UK
Walking School Bus - Nebraska	Heelan et al. 2009	USA
The Sports, Play, and Recreation for Youth (SPARK) program	Herrick et al. 2012	USA
Fit for Life Boy Scouts Program	Jago et al. 2006	USA
The Bristol Girls Dance Project Feasibility Trial	Jago et al. 2012	UK
Action 3:30 (Jago et al. 2014)	Jago et al. 2014	UK
The Bristol Girls Dance Project	Jago et al. 2015	UK
Active for Life Year 5 (AFLY5)	Kipping et al. 2014	UK
The Memphis Girls' health Enrichment Multi-site Studies (GEMS)	Klesges et al. 2010	USA
KISS school-based physical activity program	Kriemler et al. 2010 & Meyer et al. 2014	Switzerland
Laukkanen (2015)	Laukkanen et al. 2015	Finland
Lee (2012)	Lee et al. 2012	Taiwan
Lubans & Morgan (2008)	Lubans & Morgan. 2008	Australia
Program X intervention	Lubans et al. 2009 & Lubans et al. 2010	Australia
Physical Activity Leaders (PALS)	Lubans et al. 2011 & Lubans et al. 2012	Australia
MacConnie (1982)	MacConnie et al. 1982	USA
School-Community Partnerships: a Cluster RCT	Madsen et al. 2013	USA
Energy Balance 4 Kids with Play RCT	Madsen et al. 2015	USA
Magnusson (2011)	Magnusson et al. 2011	Iceland
Maloney (2008)	Maloney et al. 2008	USA
STOPP Cluster RCT	Marcus et al. 2009	Sweden
McManus (2008)	McManus et al. 2008	Hong Kong

McMinn (2012)	McMinne al. 2012	UK
Meinhardt (2013)	Meinhardt et al. 2013	Switzerland
Walking School Bus - Texas (Mendoza et al. 2011)	Mendoza et al. 2011	USA
Couch Potatoes to Jumping Beans	Mhurchu et al. 2008	New Zealand
The Healthy Dads, Healthy Kids community randomzied controlled trial (2011)	Morgan et al. 2011	Australia
The Healthy Dads, Healthy Kids community randomzied controlled trial (2014)	Morgan et al. 2014	Australia
The Great Activity Programme	Morris et al. 2013	UK
Children, parents and pets exercising together (CPET)	Morrison et al. 2013	UK
Action Schools! BC	Naylor et al. 2008	Canada
Healthy School Start Study	Nyberg et al. 2015	Sweden
Healthy School Start Study II	Nyberg et al. 2016	Sweden
Y-PATH Intervention (O'Brien et al. 2013)	O'Brien et al. 2013	Ireland
BOUNCE (Behavior Opportunities Uniting Nutrition, Counseling, and Exercise) trial	Olvera et al. 2010	USA
Promoting Lifestyle Activity for Youth (PLAY) Intervention	Pangrazi et al. 2003	USA
Sigue la Huella intervention	Pardo et al. 2014	Spain
PACE+ for adolescents	Patrick et al. 2006	USA
Prochaska (2004)	Prochaska et al. 2004	USA
Reza (2014)	Reza et al. 2014	Turkey
Reznik (2015)	Reznik et al. 2015	USA
Encouraging Activity to Stimulate Young (EASY) Minds' programme	Riley et al. 2015	Australia
The EASY Minds pilot RCT	Riley et al. 2015	Australia
Robbins (2012)	Robbins et al. 2012	USA
Roemmich (2004)	Roemmich et al. 2004	USA
Roemmich (2012)	Roemmich et al. 2012	USA
Swwitch play intervention	Salmon et al. 2008	Australia
Schodielf (2005)	Schodielf et al. 2005	Australia
The Nereu Program	Serra-Paya et al. 2015	Spain
HYPPE - Helping Youth Pursue Physical Activity and Exercise (Shore et al. 2014)	Shore et al. 2014	USA
Sigmund (2012)	Sigmund et al. 2012	Czech Republic
Active Teen Leaders Avoiding Screen-time (ATLAS) cluster randomized controlled trial	Smith et al. 2014	Australia
Minnesota GEMS Pilot Study	Story et al. 2003	USA
Straker (2013)	Straker et al. 2013	Australia
Physical Activity 4 Everyone	Sutherland et al. 2013 & Sutherland et al. 2013	Australia
The APPLE project	Taylor et al. 2006	New Zealand
The Mulicomponent SPACE Study: A Cluster RCT	Toftager et al. 2014	Denmark
The MOVE Project	Tymms et al. 2016	UK

The prevention of dietary- and lifestyle-induced health effects in children and infants (IDEFICS) intervention (IDEFICS)	Verbestel et al. 2015	8 European Countries (Belgium, Cyprus, Estonia, Germany, Hungary, Italy, Spain and Sweden)
UP4FUN pilot intervention (2012)	Verloigne et al. 2012	Belgium
Verstraete (2007)	Verstraete et al. 2007	Belgium
lauft' trial	Vivien Suchert et al. 2015	Germany
Wells (2014)	Wells et al. 2014	USA
Wilson (2002)	Wilson et al. 2002	USA
Wilson (2005)	Wilson et al. 2005	USA
Active by Choice Today (ACT)	Wilson et al. 2011	USA

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APPENDIX 6: CHAPTER 6

A.6.1 PROSPERO Registration

PROSPERO
International prospective register of systematic reviews

NHS
National Institute for Health Research

Equity effects of children's school-based physical activity interventions across gender and socioeconomic position

Rebecca Love, Esther van Sluijs, Jean Adams

Citation

Rebecca Love, Esther van Sluijs, Jean Adams. Equity effects of children's school-based physical activity interventions across gender and socioeconomic position. PROSPERO 2017 CRD42017062565 Available from: http://www.crd.york.ac.uk/PROSPERO/display_record.php?ID=CRD42017062565

Review question

Are children's school-based physical activity interventions differentially effective across girls and boys?
Are school-based physical activity interventions are differentially effective across socioeconomic position (SEP) subgroups of children?

Searches

This analysis is the second stage of a scoping review (PROSPERO 2016: CRD42016034020). The original searches will be updated by searching the following databases:
- ERIC
- EMBASE
- Scopus
- PsycINFO
- OVID MEDLINE
- SPORTDiscus

Restrictions:
The following restrictions will be applied to the updated search:
- They must be English language journals;
- Population: must be children and adolescents (6-18 years of age) in school;
- They must be studies which have recruited samples from the general population (children and adolescents selected on the basis of having a specific disease, special needs or defined as obese will be excluded);
- Intervention: studies must include single or multicomponent interventions aimed at increasing children's and adolescents' levels of physical activity, primarily through the school environment;
- Study design: must be cluster randomised controlled trials with a control or minimal intervention control group;
- Outcomes: must be accelerometer-assessed physical activities in the same participants at baseline and follow-up.

Types of study to be included

Inclusion criteria:Only cluster randomised controlled trials (at the classroom or school level) will be included. Exclusion criteria:- Individually randomized controlled trials.- Non-randomized controlled trials. - Trials comparing two active intervention arms.- Interventions described as pilot or feasibility studies.

Condition or domain being studied

Physical activity during childhood and adolescence plays a critical role in promoting health and well-being and reducing future disease risk. Yet, most children and adolescents are not active enough to benefit their health.

Participants/population

Inclusion criteria:
- Children and adolescents (6-18 years of age) in school.

- Study populations recruited from the general population.
Exclusion criteria:
- Pre-school populations of children.
- Children and adolescents selected on the basis of having a specific disease or special needs.
- Studies in which participants are defined as obese, and the sample is restricted to an obese population.

Intervention(s), exposure(s)

Inclusion criteria:
- Single- or multi-component school-based interventions aimed at increasing physical activity in children.
- The intervention must of been delivered centrally through the school setting.
Exclusion criteria:
- Interventions with a duration of less than 4 weeks.
- Interventions implemented centrally in the home, the community or in a primary care setting.

Comparator(s)/control

Inclusion criteria:
- Interventions can have been compared with a control intervention (standard or usual care), or with a minimal intervention control group.
Exclusion criteria:
- Control conditions must not have included any physical activity components beyond the standardized/regular physical education curriculum.

Primary outcome(s)

Trials must have measured physical activity objectively, using accelerometers, at baseline and follow-up in the same participants.
Measurements of full day activity levels (both within and outside of school) must have been attempted.

Secondary outcome(s)

None.

Data extraction (selection and coding)

The following information on the differential effects will be extracted from all articles within the final pool of studies. Data extraction will be performed by RL with 100% being double checked for consistency by EvS. Individual data extraction sheets will be prepared for each included study.
The data to be extracted will include:
- Baseline characteristics (mean participant age, gender and SEP % of baseline sample, school setting); study design (cluster level); intervention characteristics (design, components, setting, behavioural approach, theory basis, duration intensity); accelerometer (brand and type, wear location, cut points, valid days, wear time); outcome measure, follow-up times, main intervention effect (N, mean, SD); gender differential effect (N, mean, SD for boys and girls); SEP differential effect (indicator used, how it was defined).
The authors of trials which do not report on outlined variables will be contacted by email, and re-analysis requested. After three weeks, authors who have not responded will be sent a reminder email, and a cut off point will be set two weeks after this reminder (i.e. five weeks after the initial request).

Risk of bias (quality) assessment

Two reviewers will independently quality assess all included studies using the Cochrane Collaboration's risk of bias tool. Studies will be assessed for the five domains of bias (selection, performance, attrition, detection and reporting) and classified within each as presenting a low, high or unclear risk of bias. Following the assessment of the distribution of risk of bias scores, a subset of low quality/high risk of bias trials will be excluded.

Strategy for data synthesis

Depending on the availability of homogenous data and trials, we plan to run meta-analyses to look at the differences in intervention effects by gender (girls compared to boys) and by socioeconomic position (across the three tertiles).

Analysis of subgroups or subsets

If the necessary data is available, subgroup analyses will be conducted to investigate whether different types of interventions are driving different intervention effects by gender and socioeconomic status.

Contact details for further information

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Organisational affiliation of the review

MRC Epidemiology Unit & Centre for Diet and Activity Research (CEDAR)

Review team members and their organisational affiliations

Ms Rebecca Love. Centre for Diet and Activity Research (CEDAR), MRC Epidemiology Unit
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Anticipated or actual start date

01 February 2017

Anticipated completion date

01 November 2017

Funding sources/sponsors

Centre for Diet and Activity Research (CEDAR), a UKCRC Public Health Research Centre of Excellence [RES-590-28-0002]. Funding from the British Heart Foundation, Cancer Research UK, Economic and Social Research Council, Medical Research Council, the National Institute for Health Research, and the Wellcome Trust, under the auspices of the UK Clinical Research Collaboration, is gratefully acknowledged. This work is additionally supported by the Medical Research Council [MC_UU_12015/7].

Conflicts of interest

None known

Language

English

Country

England

Stage of review

Review_Ongoing

Subject index terms status

Subject indexing assigned by CRD

Subject index terms

Cardiorespiratory Fitness; Child; Exercise; Gender Identity; Health Behavior; Health Promotion; Health Status Disparities; Humans; Physical Fitness; School Health Services; Schools; Socioeconomic Factors

Date of registration in PROSPERO

18 May 2017

Date of publication of this version

18 May 2017

Details of any existing review of the same topic by the same authors

This analysis is the second stage of a scoping review (PROSPERO 2016: CRD42016034020).

Stage of review at time of this submission

Stage	Started	Completed
Preliminary searches	Yes	Yes
Piloting of the study selection process	Yes	Yes
Formal screening of search results against eligibility criteria	Yes	No
Data extraction	Yes	No
Risk of bias (quality) assessment	Yes	No
Data analysis	No	No

Versions

18 May 2017

A.6.2 Medline Search Strategy

Medline
1. (child* or children or childhood or kids or adolescen* or "young person*" or "young people" or teen* or youth* or boy* or girl* or juvenile).ti,ab. 2. exp child/ 3. exp adolescent/ 4. 2 or 3 5. (child or adolescent).ti,ab. 6. 1 or 5 7. ("physical* activ*" or "physical activity" or sport* or cycling or bicycling or bicycle* or walk* or "physical education" or "physical training" or exercis* or "energy expenditure" or danc* or "physical inactivity" or "physical fitness" or lifestyle or "active travel" or commut* or "aerobic fitness").ti,ab. 8. exp motor activity/ 9. exp sports/ 10. exp exercise/ 11. exp physical exertion/ 12. exp "physical education and training"/ 13. 8 or 9 or 10 or 11 or 12 14. (motor activity or sports or exercise or physical exertion or "physical education and training").ti,ab. 15. 7 or 14 16. ("clinical trial" or "control* trial" or controlled or randomi#ation or randomised or randomized or randomization or randomly or randomisation or rct or "randomi#ed controlled trial*" or "randomised controlled trial" or "randomized controlled trial" or "cluster randomized controlled trial" or "group-randomized controlled trial" or "randomized controlled study" or "randomised controlled study" or "random* sample" or trial* or evaluation or effect* or control* or cluster or intervention).ti,ab. 17. exp randomized controlled trial/ 18. exp clinical trial/ 19. exp randomized controlled trials as topic/ 20. exp clinical trial as topic/ 21. 17 or 18 or 19 or 20 22. (randomized controlled trial or clinical trial or randomized controlled trials as topic or clinical trial as topic).ti,ab. 23. 16 or 22 24. ("case study" or "case report" or "abstract report" or letter).ti,ab. 25. exp letter/ 26. exp historical article/ 27. exp case report/ 28. 25 or 26 or 27 29. (letter or historical article or case report).ti,ab. 30. 24 or 29 31. 23 not 30 32. (accelerometer or accelerometry or accelerometers or accelerometer-assessed or "counts per minute" or CPM or triaxial or Actigraph or Yamax or Actiheart or Omron, sensewear or caltrac or walk4life or ideea or actireg or lifecorder or tritrac or genea or stepwatch or actical or actiwatch or rt3 or activpal or actimarker or dynaport or CSA or MTI or pedometer or "heart rate" or pedometry or pedometers or uniaxial or actigraphy or undimensional or "objectively measur*" or "SenseWear Pro2 Armband" or "motion sensor data" or "activity monitor" or MVPA).ti,ab. 33. exp monitoring, ambulatory/ 34. exp actigraphy/ 35. 33 or 34 36. (monitoring, ambulatory or actigraphy).ti,ab. 37. 32 or 36 38. 6 and 15 and 31 and 37 39. 6 and 15 and 31 and 37 40. limit 39 to English Language + Year limitation: 2016 – 2017

A.6.3 Data extracted

- Trial name
- Authors
- Publication year
- Journal of publication
- Country of implementation
- Mean age of participants
- Type of school
- Number of schools total
- Unit of randomization
- Number of clusters (Intervention group)
- Number of clusters (Control group)
- Intervention components (Education, social environment, physical environment)
- Intervention setting (School or school plus other contexts (home, community)
- Behavioural approach (Physical activity only or physical activity and other behaviours)
- Is the intervention theory based?
- What is the proposed theory?
- Duration of intervention (total weeks)
- Duration (number of sessions/week)
- MVPA accelerometer cut point
- Timing of measurements (Time 1 (Baseline), Time 2, Time 3)
- Main effect
    - Time 1: N, mean, SD for intervention and control group
    - Time 2: N, mean, SD for intervention and control group
    - Time 3: N, mean, SD for intervention and control group
- Gender effect - is the intervention targeted by gender?
    - Girls effect:
        - Time 1: N, mean, SD for intervention and control group
        - Time 2: N, mean, SD for intervention and control group
        - Time 3: N, mean, SD for intervention and control group
    - Boys effect:
        - Time 1: N, mean, SD for intervention and control group
        - Time 2: N, mean, SD for intervention and control group
        - Time 3: N, mean, SD for intervention and control group
- Socioeconomic position effect - is the intervention targeted by SEP (If yes by individual, school or community SEP)
    - Low SEP tertile
        - Time 1: N, mean, SD for intervention and control group
        - Time 2: N, mean, SD for intervention and control group
        - Time 3: N, mean, SD for intervention and control group
    - Middle SEP tertile
        - Time 1: N, mean, SD for intervention and control group
        - Time 2: N, mean, SD for intervention and control group
        - Time 3: N, mean, SD for intervention and control group
    - High SEP tertile
        - Time 1: N, mean, SD for intervention and control group
        - Time 2: N, mean, SD for intervention and control group
        - Time 3: N, mean, SD for intervention and control group
    - Two or three groups?
    - Description for SEP indicator
        - Indicator/cut off for low SEP
        - Indicator/cut off for middle SEP
        - Indicator/cut off for high SEP

A.6.4 Template of data request form utilized

Study name: __________________

Corresponding author: _____________

Outlined in the tables below is the information required. We ask all outcomes be in mean minutes of MVPA/day (across all valid days).

<u>Main Effect:</u>

	Mean	N (sample size)	Std. Deviation
Time 1 (Baseline)			
Intervention			
Control			
Time 2 (Follow-up 1)			
Intervention			
Control			
Time 3 (Follow-up 2)			
Intervention			
Control			

<u>Stratified by gender:</u>

	Girls		
	N	**Mean mins MVPA/day**	**Std. Deviation**
Time 1 (Baseline)			
Intervention			
Control			
Time 2 (Follow-up 1)			
Intervention			
Control			
Time 3 (Follow-up 2)			
Intervention			
Control			

	Boys		
	N	**Mean mins MVPA/day**	**Std. Deviation**
Time 1 (Baseline)			
Intervention			
Control			
Time 2 (Follow-up 1)			
Intervention			
Control			
Time 3 (Follow-up 2)			
Intervention			
Control			

<u>Stratified by individual indicator of Socioeconomic Status (SES)</u>

We ask for the outcome to be presented in 3 groups (if this is not feasible, please provide based on 2 groups).

Preferentially, we would like this by indicator of 1) parental education (preferably maternal). If this is not available, we ask for the data by 2) an area-based marker of deprivation (e.g. Index of Multiple Deprivation or other postal code based indices), or alternatively 3) household income equivalised for household composition.

If this is not possible and you have other individual indicators of SES we ask you to get in touch to discuss.

SES indicator Used:
Description of indicator:
Criteria used to assign Group 1 (Low SES)

Criteria used to assign Group 2 (Middle SES)
Criteria used to assign Group 3 (High SES)

Low SES group (Group 1)

	N	Mean mins MVPA/day	Std. Deviation
Time 1 (Baseline)			
Intervention			
Control			
Time 2 (Follow-up 1)			
Intervention			
Control			
Time 3 (Follow-up 2)			
Intervention			
Control			

Middle SES group (Group 2)

	N	Mean mins MVPA/day	Std. Deviation
Time 1 (Baseline)			
Intervention			
Control			
Time 2 (Follow-up 1)			
Intervention			
Control			
Time 3 (Follow-up 2)			
Intervention			
Control			

High SES group (Group 3)

	N	Mean mins MVPA/day	Std. Deviation
Time 1 (Baseline)			
Intervention			
Control			
Time 2 (Follow-up 1)			
Intervention			
Control			
Time 3 (Follow-up 2)			
Intervention			
Control			

A.6.5 Formula for imputing the standard deviation of the change

$$SD_{E,change} = \sqrt{SD^2_{E,baseline} + SD^2_{E,final} - (2 \times Corr \times SD_{E,baseline} \times SD_{E,final})},$$

A.6.6 Trials excluded in full text screening

Trial	Citation	Reason for exclusion
Action 3:30	Jago, R., Sebire, S. J., Davies, B., Wood, L., Edwards, M. J., Banfield, K., … J.E., P. (2014). Randomised feasibility trial of a teaching assistant led extracurricular physical activity intervention for 9 to 11 year olds: Action 3:30. The International Journal of Behavioral Nutrition and Physical Activity, 11(1), no pagination–no pagination. Retrieved from http://www.ijbnpa.org/content/11/1/114	Feasibility/ pilot
Beat the Street	Coombes E, Jones A. Gamification of active travel to school: A pilot evaluation of the Beat the Street physical activity intervention. Heal Place [Internet]. 2016;39:62–9. Available from: http://dx.doi.org/10.1016/j.healthplace.2016.03.001	Feasibility/ pilot
Bristol Girls Feasibility Trial	Jago, R., Edwards, M. J., Sebire, S. J., Tomkinson, K., Bird, E. L., Banfield, K., … J.E., P. (2015). Effect and cost of an after-school dance programme on the physical activity of 11-12 year old girls: The Bristol Girls Dance Project, a school-based cluster randomised controlled trial Jago R. International Journal of Behavioral Nutrition and Physical Activity, 12(1), no pagination–no pagination. http://doi.org/10.1186/s12966-015-0289-y	Feasibility/ pilot
Couch Potatoes to Jumping Beans	Mhurchu, C. N., Maddison, R., Jiang, Y., Jull, A., Prapavessis, H., & Rodgers, A. (2008). Couch potatoes to jumping beans: A pilot study of the effect of active video games on physical activity in children. International Journal of Behavioral Nutrition and Physical Activity, 5(8). http://doi.org/10.1186/1479	Feasibility/ pilot
Crouter (2015)	Crouter, S. E., de Ferranti, S. D., Whiteley, J., Steltz, S. K., Osganian, S. K., Feldman, H. A., & Hayman, L. L. (2015). Effect on physical activity of a randomized afterschool intervention for Inner City Children in 3rd to 5th grade. PLoS ONE, 10(10), e0141584–e0141584. Retrieved from http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=prem&NEWS=N&AN=26510013	Feasibility/ pilot
Dudley (2010)	Dudley, D. A., Okely, A. D., Pearson, P., & Peat, J. (2010). Engaging adolescent girls from linguistically diverse and low income backgrounds in school sport: A pilot randomised controlled trial. Journal of Science and Medicine in Sport, 13(2), 217–224. http://doi.org/10.1016/j.jsams.2009.04.008	Feasibility/ pilot
EASY Minds	Riley, N., Lubans, D. R., Morgan, P. J., & Young, M. (2015). Outcomes and process evaluation of a programme integrating physical activity into the primary school mathematics curriculum: The EASY Minds pilot randomised controlled trial. Journal of Science and Medicine in Sport / Sports Medicine Australia, 18(6), 656–661. Retrieved from http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=prem&NEWS=N&AN=25304445	Feasibility/ pilot
Fit4fun Pilot Study	Eather N, Morgan PJ, Lubans DR. Feasibility and preliminary efficacy of the Fit4Fun intervention for improving physical fitness in a sample of primary school children: a pilot study. Phys Educ Sport Pedagog. 2013;18(4):389–411.	Feasibility/ pilot
Hands (2011)	Hands, B., Larkin, D., Rose, E., Parker, H., & Smith, A. (2011). Can Young Children Make Active Choices? Outcomes of a Feasibility Trial in Seven-Year-Old Children. Early Child Development and Care, 181(5), 625–637.	Feasibility/ pilot

	Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=EJ923980&site=ehost-live&scope=site	
Healthy Homework pilot study	Duncan, S., McPhee, J. C., Schluter, P. J., Zinn, C., Smith, R., & Schofield, G. (2011). Efficacy of a compulsory homework programme for increasing physical activity and healthy eating in children: The Healthy Homework pilot study. The International Journal of Behavioral Nutrition and Physical Activity, 8, no pagination–no pagination. http://doi.org/10.1186/1479-5868-8-127	Feasibility/ pilot
Maloney (2008)	Maloney, A. E., Bethea, T. C., Kelsey, K. S., Marks, J. T., Paez, S., Rosenberg, A. M., … Sikich, L. (2008). A pilot of a video game (DDR) to promote physical activity and decrease sedentary screen time. Obesity, 16(9), 2074–2080. http://doi.org/10.1038/oby.2008.295	Feasibility/ pilot
Memphis GEMS Pilot Trial	Beech, B. M., Klesges, R. C., Kumanyika, S. K., Murray, D. M., Klesges, L., McClanahan, B., … B., M.-A. M. M.-A. M. (2003). Child- and parent-targeted interventions: the Memphis GEMS pilot study. Ethnicity & Disease, 13(1 Suppl 1), S1–53. Retrieved from http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=emed6&NEWS=N&AN=2003168621	Feasibility/ pilot
Minnesota GEMS Pilot Study	Story, M., Sherwood, N. E., Himes, J. H., Davis, M., Jacobs, D. R., Cartwright, Y., … Rochon, J. (2003). An After-school obesity prevention program for africian-americian girls: The Minnesota GEMS Pilot Study. Ethnicity & Disease, 13.	Feasibility/ pilot
Reznik (2015)	Reznik, M., Wylie-Rosett, J., Kim, M., & Ozuah, P. O. (2015). A classroom-based physical activity intervention for urban kindergarten and first-grade students: A feasibility study. Childhood Obesity, 11(3), 314–324. http://doi.org/10.1089/chi.2014.0090	Feasibility/ pilot
Robbins (2012)	Robbins, L. B., Pfeiffer, K. A., Maier, K. S., Lo, Y.-J., & Wesolek, S. M. (2012). Pilot Intervention to Increase Physical Activity Among Sedentary Urban Middle School Girls: A Two-Group Pretest-Posttest Quasi-Experimental Design. Journal of School Nursing, 28(4), 302–315. http://doi.org/10.1177/1059840512438777	Feasibility/ pilot
The EASY Minds pilot RCT	Riley, N., Lubans, D. R., Morgan, P. J., & Young, M. (2015). Outcomes and process evaluation of a programme integrating physical activity into the primary school mathematics curriculum: The EASY Minds pilot randomised controlled trial. Journal of Science and Medicine in Sport / Sports Medicine Australia, 18(6), 656–661. Retrieved from http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=prem&NEWS=N&AN=25304445	Feasibility/ pilot
Walking School Bus - Texas (Mendoza et al. 2011)	Mendoza, J., Watson, K., Baranowski, T., Nicklas, T., Uscanga, D., Hanfling, M. (2011). Pediatrics	Feasibility/ pilot
Wilson (2005)	Wilson, D. K., Evans, A. E., Williams, J., Mixon, G., Sirard, J. R., Pate, R., … J.R., S. (2005). A preliminary test of a student-centered intervention on increasing physical activity in underserved adolescents. Annals of Behavioral Medicine, 30(2), 119–124. http://doi.org/10.1207/s15324796abm3002_4	Feasibility/ pilot

Van Kann et al. (2016)	Van Kann D, Kremers S, de Vries N, de Vries S. The effect of a school-centered multicomponent intervention on daily physical activity and sedentary behavior in primary school children: The Active Living study. Prev Med (Baltim) [Internet]. 2016;89:64–9.	Intervention design
Prochaska (2004)	Prochaska, J. J., & Sallis, J. F. (2004). A Randomized Controlled Trial of Single Versus Multiple Health Behavior Change: Promoting Physical Activity and Nutrition Among Adolescents. Health Psychology, 23(3), 314–318. http://doi.org/10.1037/0278-6133.23.3.314	Intervention design
Beets et al. (2016)	Beets, M. W., Weaver, R. G., Turner-McGrievy, G., Huberty, J., Ward, D. S., Pate, R. R., … Beighle, A. (2015). Making policy practice in afterschool programs: A randomized controlled trial on physical activity changes. American Journal of Preventive Medicine, 48(6), 694–706. http://doi.org/10.1016/j.amepre.2015.01.012	Outcome (Not full day)
Cradock et al. (2016)	Cradock, A. L., Barrett, J. L., Giles, C. M., Lee, R. M., Kenney, E. L., deBlois, M. E., … Gortmaker, S. L. (2016). Promoting Physical Activity With the Out of School Nutrition and Physical Activity (OSNAP) Initiative: A Cluster-Randomized Controlled Trial. JAMA Pediatrics, 170(2), 155–162. Retrieved from http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=prem&NEWS=N&AN=26641557	Outcome (Not full day)
Van Kann et al. (2016)	Van Kann DHH, de Vries SI, Schipperijn J, de Vries NK, Jansen MWJ, Kremers SPJ. A Multicomponent Schoolyard Intervention Targeting Children's Recess Physical Activity and Sedentary Behavior: Effects After One Year. J Phys Act Health [Internet]. 2016;1–28.	Outcome (Not full day)
It's child's play	Engelen, L., Bundy, A. C., Naughton, G., Simpson, J. M., Bauman, A., Ragen, J., … van der Ploeg, H. P. (2013). Increasing physical activity in young primary school children—It's child's play: A cluster randomised controlled trial. Preventive Medicine: An International Journal Devoted to Practice and Theory, 56(5), 319–325. http://doi.org/10.1016/j.ypmed.2013.02.007	Outcome (Not full day)
Martin et al. (2016)	Martins S, Palmeira A, Minderico C. Longitudinal outcomes of a school-based lifestyle promotion program: Preliminary results [Internet]. Journal of Adolescent Health. Elsevier USA; 2011. p. S79–S79. Available from: http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=emed10&NEWS=N&AN=70352287	Outcome (Not full day)
STAR Programme	Ha, A. S., Burnett, A., Sum, R., Medic, N., & Ng, J. Y. Y. (2015). Outcomes of the Rope Skipping "STAR" Programme for Schoolchildren. Journal of Human Kinetics, 45, 233–240. http://doi.org/10.1515/hukin-2015-0024	Outcome (Not full day)
STOPP	Marcus, C., Nyberg, G., Nordenfelt, A., Karpmyr, M., Kowalski, J., & Ekelund, U. (2009). A 4-year, cluster-randomized, controlled childhood obesity prevention study: STOPP. International Journal of Obesity, 33(4), 408–417. http://doi.org/10.1038/ijo.2009.38	Outcome (Not full day)
Weaver et al. (2016)	Weaver RG, Moore JB, Huberty J, Freedman D, Turner-McGrievy B, Beighle A, et al. Process Evaluation of Making HEPA Policy Practice: A Group Randomized Trial. Health Promot Pract. 2016;17(5):631–47.	Outcome (Not full day)
Wells (2014)	Wells, N. M., Myers, B. M., & Henderson Jr., C. R. (2014). School gardens and physical activity: A randomized controlled trial of low-income elementary schools. Preventive Medicine, 69, Supple, S27–S33. http://doi.org/10.1016/j.ypmed.2014.10.012	Outcome (Not full day)

Aburto (2011)	Aburto, N. J., Fulton, J. E., Safdie, M., Duque, T., Bonvecchio, A., & Rivera, J. A. (2011). Effect of a school-based intervention on physical activity: Cluster-randomized trial. Medicine and Science in Sports and Exercise, 43(10), 1898–1906. http://doi.org/10.1249/MSS.0b013e318217ebec	Outcome (Not via accelerometer)
Eyre (2016)	Eyre, E. L. J., Cox, V. M., Birch, S. L., & Duncan, M. J. (2016). An integrated curriculum approach to increasing habitual physical activity in deprived South Asian children. European Journal of Sport Science, 16(3), 381–390. http://doi.org/10.1080/17461391.2015.1062565	Outcome (Not via accelerometer)
FATaintPHAT	Ezendam, N. P. M., Brug, J., Oenema, A., JJ, R., I, A., PM, G., … I, D. B. (2012). Evaluation of the Web-Based Computer-Tailored FATaintPHAT Intervention to Promote Energy Balance Among Adolescents. Archives of Pediatrics & Adolescent Medicine, 166(3), 248. http://doi.org/10.1001/archpediatrics.2011.204	Outcome (Not via accelerometer)
Fit 'n' fun dudes program (2009)	Hardman, C. A., Horne, P. J., & Lowe, C. F. (2009). A home-based intervention to increase physical activity in girls: The fit "n" fun dudes program. Journal of Exercise Science and Fitness, 7(1), 1–8. http://doi.org/10.1016/S1728-869X(09)60001-0	Outcome (Not via accelerometer)
Fit 'n' fun dudes program (2011)	Hardman, C. A., Horne, P. J., & Lowe, C. F. (2011). Effects of rewards, peer-modelling and pedometer targets on children's physical activity: A school-based intervention study. Psychology and Health, 26(1), 3–21. http://doi.org/10.1080/08870440903318119	Outcome (Not via accelerometer)
Fit4fun Trial	Eather, N., Morgan, P. J., & Lubans, D. R. (2013a). Feasibility and preliminary efficacy of the Fit4Fun intervention for improving physical fitness in a sample of primary school children: a pilot study. Physical Education and Sport Pedagogy, 18(4), 389–411. http://doi.org/10.1080/17408989.2012.690375	Outcome (Not via accelerometer)
Harder-lauridsen (2014)	Harder-lauridsen, N. M., Birk, N. M., Ried-larsen, M., Juul, A., & Andersen, L. B. (2014). A randomized controlled trial on a multicomponent intervention for overweight school-aged children - Copenhagen, Denmark. BMC Pediatrics, 273(14), 1–14.	Outcome (Not via accelerometer)
lauft' trial	210. Suchert, V., Isensee, B., Sargent, J., Weisser, B., Hanewinkel, R., & Group, lauft. S. (2015). Prospective effects of pedometer use and class competitions on physical activity in youth: A cluster-randomized controlled trial. Preventive Medicine, 81, 399–404.	Outcome (Not via accelerometer)
Lee (2012)	Lee, L., Kuo, Y., Fanaw, D., Perng, S., & Juang, I. (2012). The effect of an intervention combining self efficacy theory and pedometers on promoting physical activity among adolescents. Journal of Clinical Nursing, 21(7-8), 914–922. http://doi.org/10.1111/j.1365-2702.2011.03881.x	Outcome (Not via accelerometer)
Lubans & Morgan (2008)	Lubans, D., & Morgan, P. (2008). Evaluation of an extra-curricular school sport programme promoting lifestyle and lifetime activity for adolescents. Journal of Sports Sciences, 26(5), 519–529. http://doi.org/10.1080/02640410701624549	Outcome (Not via accelerometer)
MacConnie (1982)	MacConnie, S. E., T.B., G., D.L., G., & A.E., P. I. I. I. (1982). Daily physical activity patterns of prepubertal children involved in a vigorous exercise program. International Journal of Sports Medicine, 3(4), 202–207. Retrieved from http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=emed1a&NEWS=N&AN=1983072947	Outcome (Not via accelerometer)

McManus (2008)	McManus, A. M., Masters, R. S. W., Laukkanen, R. M. T., Yu, C. C. W., Sit, C. H. P., & Ling, F. C. M. (2008). Using heart-rate feedback to increase physical activity in children. Preventive Medicine, 47(4), 402–8. http://doi.org/10.1016/j.ypmed.2008.06.001	Outcome (Not via accelerometer)
Physical Activity Leaders (PALS)	Lubans, D. R., Morgan, P. J., Aguiar, E. J., & Callister, R. (2011). Randomized controlled trial of the Physical Activity Leaders (PALs) program for adolescent boys from disadvantaged secondary schools. Preventive Medicine, 52(3-4), 239–246. http://doi.org/10.1016/j.ypmed.2011.01.009	Outcome (Not via accelerometer)
PLAY	Pangrazi, R. P., Beighle, A., Vehige, T., Vack, C., R.P., P., A., B., & T., V. (2003). Impact of Promoting Lifestyle Activity for Youth (PLAY) on children's physical activity. Journal of School Health, 73(8), 317–321. Retrieved from http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=emed6&NEWS=N&AN=14593948	Outcome (Not via accelerometer)
Program X	Lubans, D. R., Morgan, P. J., Callister, R., Collins, C. E., & Plotnikoff, R. C. (2010). Exploring the mechanisms of physical activity and dietary behavior change in the program x intervention for adolescents. The Journal of Adolescent Health : Official Publication of the Society for Adolescent Medicine, 47(1), 83–91. http://doi.org/10.1016/j.jadohealth.2009.12.015	Outcome (Not via accelerometer)
Reza (2014)	Reza, S., Tahir, W. M., Zakaria, W., Agency, M. N., & Agency, N. (2014). Impact of Social-Ecological Intervention on Physical Activity Knowledge and Behaviors of Rural Students. Journal of Physical Activity and Health.	Outcome (Not via accelerometer)
Schodielf (2005)	Schofield, L., Mummery, W. K., & Schofield, G. (2005). Effects of a controlled pedometer-intervention trial for low-active adolescent girls. Medicine and Science in Sports and Exercise, 37(8), 1414–1420. Retrieved from http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=emed7&NEWS=N&AN=2005390591	Outcome (Not via accelerometer)
Shore (2014) [HYPPE]	Shore, S. M., Sachs, M. L., DuCette, J. P., & Libonati, J. R. (2014). Step-Count Promotion Through a School-Based Intervention. Clinical Nursing Research, 23(4), 402–420. http://doi.org/10.1177/1054773813485240	Outcome (Not via accelerometer)
SWITCH what you Do, View and Chew	Gentile, D. A., Welk, G., Eisenmann, J. C., Reimer, R. A., Walsh, D. A., Russell, D. W., … S., S. (2009). Evaluation of a multiple ecological level child obesity prevention program: Switch what you Do, View, and Chew. BMC Medicine, 7, 49. http://doi.org/10.1186/1741-7015-7-49	Outcome (Not via accelerometer)
AIMFIT Pragmatic Randomized Controlled Trial	Direito, A., Jiang, Y., Whittaker, R., & Maddison, R. (2015). Apps for IMproving FITness and Increasing Physical Activity Among Young People: The AIMFIT Pragmatic Randomized Controlled Trial. Journal of Medical Internet Research, 17(8), e210–e210. http://doi.org/10.2196/jmir.4568	Setting (not centrally school based)
Backlund (2011)	Bäcklund, C., Sundelin, G., & Larsson, C. (2011). Effects of a 2-year lifestyle intervention on physical activity in overweight and obese children. Advances in Physiotherapy, 13(3), 97–109. http://doi.org/10.3109/14038196.2011.562540	Setting (not centrally school based)
Baranowski (2011)	Baranowski, T., Baranowski, J., Thompson, D., Buday, R., Jago, R., Griffith, M. J., … Watson, K. B. (2011). Video game play, child diet, and physical activity behavior change: A randomized clinical trial. American Journal of	Setting (not centrally

	Preventive Medicine, 40(1), 33–38. http://doi.org/10.1016/j.amepre.2010.09.029	school based)
Baranowski (2012)	Baranowski, T., Abdelsamad, D., Baranowski, J., O'Connor, T. M., Thompson, D., Barnett, A., … Chen, T.-A. (2012). Impact of an active video game on healthy children's physical activity. Pediatrics, 129(3), e636–e642. Retrieved from http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=medl&NEWS=N&AN=22371457	Setting (not centrally school based)
BOUNCE	Olvera, N., Bush, J. A., Sharma, S. V, Knox, B. B., Scherer, R. L., & Butte, N. F. (2010). BOUNCE: A community-based mother-daughter healthy lifestyle intervention for low-income Latino families. Obesity, 18(Suppl 1), S102–S104. http://doi.org/10.1038/oby.2009.439	Setting (not centrally school based)
Challenge!	Black, M. M., Hager, E. R., Le, K., Anliker, J., Arteaga, S. S., DiClemente, C., … Wang, Y. (2010). Challenge! Health promotion/obesity prevention mentorship model among urban, Black adolescents. Pediatrics, 126(2), 280–288. http://doi.org/10.1542/peds.2009-1832	Setting (not centrally school based)
Chen (2010)	Chen, J. L., Weiss, S., Heyman, M. B., & Lustig, R. H. (2010). Efficacy of a child-centred and family-based program in promoting healthy weight and healthy behaviors in Chinese American children: A randomized controlled study. Journal of Public Health, 32(2), 219–229. http://doi.org/10.1093/pubmed/fdp105	Setting (not centrally school based)
CPET	Morrison, R., Reilly, J. J., Penpraze, V., Westgarth, C., Ward, D. S., Mutrie, N., … Yam, P. S. (2013). Children, parents and pets exercising together (CPET): exploratory randomised controlled trial. BMC Public Health, 13, 1096. Retrieved from http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=medl&NEWS=N&AN=24279294	Setting (not centrally school based)
Finkelstein (2013)	Finkelstein, E. A., Y.-T., T., R., M., C.-F., L., S.-S., G., Finkelstein, E. A., … Saw, S.-M. (2013). A cluster randomized controlled trial of an incentive-based outdoor physical activity program. The Journal of Pediatrics, 163(1), 167–72.e1. Retrieved from http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=medl&NEWS=N&AN=23415616	Setting (not centrally school based)
Fit for Life Boy Scouts Program	Jago, R., Baranowski, T., Baranowski, J. C., Thompson, D., Cullen, K. W., Watson, K., & Liu, Y. (2006). Fit for Life Boy Scout badge: Outcome evaluation of a troop and Internet intervention. Preventive Medicine: An International Journal Devoted to Practice and Theory, 42(3), 181–187. http://doi.org/10.1016/j.ypmed.2005.12.010	Setting (not centrally school based)
Gortmaker (2012)	Gortmaker, S. L., Lee, R. M., Mozaffarian, R. S., Sobol, A. M., Nelson, T. F., Roth, B. A., & Wiecha, J. L. (2012). Effect of an after-school intervention on increases in children's physical activity. Medicine and Science in Sports and Exercise, 44(3), 450–457. http://doi.org/10.1249/MSS.0b013e3182300128	Setting (not centrally school based)
Graves (2010)	Graves, L., Ridgers, N., Atkinson, G., Stratton, G. (2010). The Effect of Active Video Gaming on Children's Physical Activity , Behavior Preferences and Body Composition. Pediatric Excercise Science, 22(April 2016), 535–546.	Setting (not centrally school based)

Healthy Dads, Healthy Kids (2011)	Morgan, P. J., Lubans, D. R., Callister, R., Okely, A. D., Burrows, T. L., Fletcher, R., & Collins, C. E. (2011). The Healthy Dads, Healthy Kids randomized controlled trial: Efficacy of a healthy lifestyle program for overweight fathers and their children. International Journal of Obesity (2005), 35(3), 436–447. Retrieved from http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=med5&NEWS=N&AN=20697417	Setting (not centrally school based)
Healthy Dads, Healthy Kids (2014)	Morgan, P. J., Collins, C. E., Plotnikoff, R. C., Callister, R., Burrows, T., Fletcher, R., … Lubans, D. R. (2014). The "Healthy Dads, Healthy Kids" community randomized controlled trial: A community-based healthy lifestyle program for fathers and their children. Preventive Medicine: An International Journal Devoted to Practice and Theory, 61, 90–99. http://doi.org/10.1016/j.ypmed.2013.12.019	Setting (not centrally school based)
Laukkanen (2015)	Laukkanen, A., Juhani Pesola, A., Heikkinen, R., Kaarina Sääkslahti, A., & Finni, T. (2015). Family-based cluster randomized controlled trial enhancing physical activity and motor competence in 4-7-year-old children. PLoS ONE, 10(10), no pagination–no pagination. http://doi.org/10.1371/journal.pone.0141124	Setting (not centrally school based)
Lifestyle triple P	Gerards, S. M. P. L., Dagnelie, P. C., Gubbels, J. S., van Buuren, S., Hamers, F. J. M., Jansen, M. W. J., … Kremers, S. P. J. (2015). The effectiveness of lifestyle triple P in the Netherlands: a randomized controlled trial. PloS One, 10(4), e0122240–e0122240. Retrieved from http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=medl&NEWS=N&AN=25849523	Setting (not centrally school based)
Memphis GEMS	Klesges, R., Obarzanek, E., Kumanyika, S., Murray, D., Klesges, L., Relyea, G., … Slawson, D. L. (2014). The Memphis Girls' health Enrichment Multi-site Studies (GEMS). Archives of Pediatrics and Adolescent Medicine, 164(11), 1007–1014.	Setting (not centrally school based)
Nereu program	Serra-Paya, N., Ensenyat, A., Castro-Vinuales, I., Real, J., Sinfreu-Bergues, X., Zapata, A., … Teixido, C. (2015). Effectiveness of a Multi-Component Intervention for Overweight and Obese Children (Nereu Program): A Randomized Controlled Trial. PloS One, 10(12), e0144502–e0144502. Retrieved from http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=prem&NEWS=N&AN=26658988	Setting (not centrally school based)
PACE+	Patrick, K., KJ, C., GJ, N., & al, et. (2006). Randomized controlled trial of a primary care and home-based intervention for physical activity and nutrition behaviors: Pace+ for adolescents. Archives of Pediatrics & Adolescent Medicine, 160(2), 128–136. http://doi.org/10.1001/archpedi.160.2.128	Setting (not centrally school based)
Roemmich (2004)	Roemmich, J. N., Gurgol, C. M., & Epstein, L. H. (2004). Open-Loop Feedback Increases Physical Activity of Youth. Medicine & Science in Sports & Exercise, 36(4), 668–673. http://doi.org/10.1249/01.MSS.0000121947.59529.3B	Setting (not centrally school based)
Roemmich (2012)	Roemmich, J. N., Lobarinas, C. L., Barkley, J. E., White, T. M., Paluch, R., & Epstein, L. H. (2012). Use of an open-loop system to increase physical activity. Pediatric Exercise Science, 24(3), 384–398. Retrieved from http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=medl&NEWS=N&AN=22971555	Setting (not centrally school based)

School-Community Partnerships	Madsen, K., Thompson, H., Adkins, A., & Crawford, Y. (2013). School-Community Partnerships: A Cluster-Randomized Trial of an After-School Soccer Program. JAMA Pediatrics, 167(4), 321. http://doi.org/10.1001/jamapediatrics.2013.1071	Setting (not centrally school based)
Straker (2013)	Straker, L. M., Abbott, R. A., & Smith, A. J. (2013). To remove or to replace traditional electronic games? A crossover randomised controlled trial on the impact of removing or replacing home access to electronic games on physical activity and sedentary behaviour in children aged 10-12 years. BMJ Open, 3(6), no pagination–no pagination. http://doi.org/10.1136/bmjopen-2013-002629	Setting (not centrally school based)
The Family Project	32. Coppins, D. F., Margetts, B. M., Fa, J. L., Brown, M., Garrett, F., & Huelin, S. (2011). Effectiveness of a multi-disciplinary family-based programme for treating childhood obesity (the Family Project). European Journal of Clinical Nutrition, 65(8), 903–909. http://doi.org/10.1038/ejcn.2011.43	Setting (not centrally school based)
Web ABC study	Chen, J. L., Weiss, S., Heyman, M. B., Cooper, B., & Lustig, R. H. (2011). The efficacy of the web-based childhood obesity prevention program in Chinese American adolescents (Web ABC study). Journal of Adolescent Health, 49(2), 148–154. http://doi.org/10.1016/j.jadohealth.2010.11.243	Setting (not centrally school based)
Wilson (2002)	Wilson, D. K., Friend, R., Teasley, N., Green, S., Reaves, I. L., & Sica, D. A. (2002). Motivational versus social cognitive interventions for promoting fruit and vegetable intake and physical activity in African American adolescents. Annals of Behavioral Medicine : A Publication of the Society of Behavioral Medicine, 24(4), 310–319. Retrieved from http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=med4&NEWS=N&AN=12434942	Setting (not centrally school based)
Meinhardt (2013)	Meinhardt, U., Witassek, F., Petrò, R., Fritz, C., & Eiholzer, U. (2013). Strength training and physical activity in boys: a randomized trial. Pediatrics, 132(6), 1105–1111. http://doi.org/10.1542/peds.2013-1343	Study design (not individually randomised)
Action Schools! BC	Naylor, P.-J., Macdonald, H. M., Warburton, D. E. R., Reed, K. E., McKay, H. A., H.M., M., … K.E., R. (2008). An active school model to promote physical activity in elementary schools: Action schools! BC Naylor P.-J. British Journal of Sports Medicine, 42(5), 338–343. http://doi.org/10.1136/bjsm.2007.042036	Study design (not RCT)
APPLE	Taylor, R. W., Mcauley, K. A., Barbezat, W., Strong, A., Williams, S. M., & Mann, J. I. (2007). APPLE Project: 2-y findings of a community-based obesity prevention program in primary school – age children, (1).	Study design (not RCT)
Boston Active School Day policy	Cradock, A. L., Barrett, J. L., Carter, J., McHugh, A., Sproul, J., Russo, E. T., … Gortmaker, S. L. (2014). Impact of the Boston Active School Day policy to promote physical activity among children. American Journal of Health Promotion : AJHP, 28(3 Supplement), S54–S64. http://doi.org/10.4278/ajhp.130430-QUAN-204	Study design (not RCT)
Carson (2014)	Carson, R. L., Castelli, D. M., Pulling Kuhn, A. C., Moore, J. B., Beets, M. W., Beighle, A., … Glowacki, E. M. (2014). Impact of trained champions of comprehensive school physical activity programs on school physical activity offerings, youth physical activity and sedentary behaviors. Preventive Medicine, 69(S), S12–S19. http://doi.org/10.1016/j.ypmed.2014.08.025	Study design (not RCT)

Copenhagen School Child Intervention Study	Bugge, A., El-Naaman, B., Dencker, M., Froberg, K., Holme, I. M. K., McMurray, R. G., & Andersen, L. B. (2012). Effects of a three-year intervention: the Copenhagen School Child Intervention Study. Medicine and Science in Sports and Exercise, 44(7), 1310–1317. Retrieved from http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=medl&NEWS=N&AN=22297806	Study design (not RCT)
D'Haese (2015)	D'Haese, S., Van Dyck, D., De Bourdeaudhuij, I., Deforche, B., & Cardon, G. (2015). Organizing "Play Streets" during school vacations can increase physical activity and decrease sedentary time in children. The International Journal of Behavioral Nutrition and Physical Activity, 12(1), 171. http://doi.org/10.1186/s12966-015-0171-y	Study design (not RCT)
Dimitriou (2011)	Dimitriou, M., Michalopoulou, M., Gourgoulis, V., & Aggelousis, N. (2011). Participation in community-based sport skills learning programmes, physical activity recommendations and health-related fitness for children in Greece. Sport Sciences for Health, 6(2-3), 93–102. http://doi.org/10.1007/s11332-011-0103-4	Study design (not RCT)
Erwin (2011)	Erwin, H. E., Abel, M. G., Beighle, A., & Beets, M. W. (2011). Promoting children's health through physically active math classes: a pilot study. Health Promotion Practice, 12(2), 244–251. http://doi.org/10.1177/1524839909331911	Study design (not RCT)
Great Activity Programme	Morris, J. G., Gorely, T., Sedgwick, M. J., Nevill, A., Nevill, M. E., J.G., M., … A., N. (2013). Effect of the Great Activity Programme on healthy lifestyle behaviours in 7-11 year olds. Journal of Sports Sciences, 31(12), 1280–1293. Retrieved from http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=emed11&NEWS=N&AN=23656302	Study design (not RCT)
GreatFun2Run	Gorely, T., Morris, J. G., Musson, H., Brown, S., Nevill, A., & Nevill, M. E. (2011). Physical activity and body composition outcomes of the GreatFun2Run intervention at 20 month follow-up. International Journal of Behavioral Nutrition and Physical Activity, 8, no pagination–no pagination. http://doi.org/10.1186/1479-5868-8-74	Study design (not RCT)
IDEFICS	Verbestel, V., De Henauw, S., Barba, G., Eiben, G., Gallois, K., Hadjigeorgiou, C., … De Bourdeaudhuij, I. (2015). Effectiveness of the IDEFICS intervention on objectively measured physical activity and sedentary time in European children. Obesity Reviews : An Official Journal of the International Association for the Study of Obesity, 16 Suppl 2, 57–67. http://doi.org/10.1111/obr.12348	Study design (not RCT)
McMinn (2012)	McMinn, D., Rowe, D. A., Murtagh, S., & Nelson, N. M. (2012). The effect of a school-based active commuting intervention on children's commuting physical activity and daily physical activity. Preventive Medicine, 54(5), 316–318. http://doi.org/10.1016/j.ypmed.2012.02.013	Study design (not RCT)
Mebane on the Move Intervention	Benjamin Neelon SE, Namenek Brouwer RJ, Østbye T, Evenson KR, Neelon B, Martinie A, et al. A Community-Based Intervention Increases Physical Activity and Reduces Obesity in School-Age Children in North Carolina. Child Obes [Internet]. 2015;11(3):297–303. Available from: http://online.liebertpub.com/doi/10.1089/chi.2014.0130	Study design (not RCT)

Sigmund (2012)	Sigmund, E., El Ansari, W., & Sigmundová, D. (2012). Does school-based physical activity decrease overweight and obesity in children aged 6-9 years? A two-year non-randomized longitudinal intervention study in the Czech Republic. BMC Public Health, 12(1), 570. http://doi.org/10.1186/1471-2458-12-570	Study design (not RCT)
Sigue la Huella	Pardo, B. M., Bengoechea, E. G., Julián Clemente, J. A., & Lanaspa, E. G. (2014). Empowering adolescents to be physically active: Three-year results of the Sigue la Huella intervention. Preventive Medicine, 66, 6–11. http://doi.org/10.1016/j.ypmed.2014.04.023	Study design (not RCT)
SPARK	Sallis, J. F., McKenzie, T. L., Alcaraz, J. E., Kolody, B., Faucette, N., & Hovell, M. F. (1997). The effects of a 2-year physical education program (SPARK) on physical activity and fitness in elementary school students. Sports, Play and Active Recreation for Kids. American Journal of Public Health, 87(8), 1328–34. http://doi.org/10.2105/AJPH.87.8.1328	Study design (not RCT)
Sport for LIFE	Breslin G, Brennan D, Rafferty R, Gallagher A. The effect of a healthy lifestyle programme on 8-9 year olds from social disadvantage. Arch Dis Child [Internet]. 2012 Jul;97(7):618–24. Available from: http://adc.bmj.com/content/97/7/618.full.pdf+html	Study design (not RCT)
Walking School Bus - Nebraska	Heelan Abbey, B., Donnelly, J., Mayo, M., Welk, G., K. (2009). Evaluation of a Walking School Bus for Promoting Physical Activity in Youth. Journal of Physical Activity and Health, (6), 560–567.	Study design (not RCT)
Y-PATH Intervention (O'Brien et al. 2013)	O' Brien W, Issartel J, Belton S. Evidence for the Efficacy of the Youth-Physical Activity towards Health (Y-PATH) Intervention. Adv Phys Educ [Internet]. 2013;03(04):145–53. Available from: http://www.scirp.org/journal/doi.aspx?DOI=10.4236/ape.2013.34024	Study design (not RCT)

A.6.7 Email request responses

Active by Choice Today (ACT)	Positive – data received, included
Active for Life Year 5 (AFLY5)	Positive – data received but not in appropriate form, excluded
Andrade et al. (2014)	Positive – data received, included
ATLAS	Positive – data received, included
CHANGE!	Positive – data received, included
Drummy et al. 2016	Positive – data received, included
Energy Balance 4 Kids with Play	Negative – data not received, excluded
Healthy School Start 1	Positive – data received, included
Healthy School Start 2	Positive – data received, included
HEIA Study	Positive – data received, included
IMPACT	Negative – data not received, excluded
KISS	Positive – data received, included
Magnusson et al. 2011	Negative – data not received, excluded
MOVE Project	Positive – data received, included
NEAT	Positive – data received, included
PAAC	Positive – data received but not in appropriate form, excluded
Pathways	Negative – data not received, excluded
Physical Activity 4 Everyone	Positive – data received, included
SCORES	Positive – data received, included
SPACE	Positive – data received, included
Swwitch play	Negative – data not received, excluded
The Active Smarter Kids Intervention	Positive – data received, included
The Bristol Girls Dance Project	Positive – data received, included
UP 4 FUN Pilot Intervention	Positive – data received, included
Verstrate et al 2007	Positive – data requested not available, excluded

A.6.8 Characteristics of included studies

Active by Choice Today

Country of implementation	USA
Mean age	11.34 (0.5)
Type of school	Middle School
Number of schools total	24
Level of cluster randomization	School
Education components?	Yes
Social environment components?	Yes
Physical environment components?	No
Behavioural approach	PA only
Theory based? If yes what theory?	Yes, Self Determination Theory
Duration of intervention total	17 weeks
Follow up 1 (months)	2.25 (mid-intervention)
Follow-up 2 (months)	4.75
Gender targeted?	No
SEP targeted?	Yes, by school SEP

Andrade et al. (2014)

Country of implementation	Ecuador
Mean age	12.9 (0.8)
Type of school	Schools (with students in 8th or 9th year)
Number of schools total	20 (18 with accelerometer measurements)
Level of cluster randomization	School
Education components?	Yes
Social environment components?	Yes
Physical environment components?	Yes
Behavioural approach	PA and other health behaviours
Theory based? If yes what theory?	Yes, Social Cognitive Theory, Information-Motivation Behavioural Skills Model, Control Theory, Trans- Theoretical Model and Theory Of Planned Behaviour were all used
Duration of intervention total	28 months (once interrupted by 2 month annual break)
Follow up 1 (months)	24 months
Gender targeted?	No
SEP targeted?	No

ATLAS

Country of implementation	Australia
Mean age	12.7 (0.5)
Type of school	Primary schools
Number of schools total	12
Level of cluster randomization	School
Education components?	Yes
Social environment components?	Yes
Physical environment components?	No
Behavioural approach	PA and other health behaviours
Theory based? If yes what theory?	Yes, Self Determination Theory and Social Cognitive Theory
Duration of intervention total	20 weeks
Follow up 1 (months)	8 months
Gender targeted?	Yes at Boys
SEP targeted?	Yes by school SEP

CHANGE!

Country of implementation	UK
Mean age	10.65 (0.3)
Type of school	Primary school
Number of schools total	12
Level of cluster randomization	School
Education components?	Yes
Social environment components?	Yes
Physical environment components?	No
Behavioural approach	PA and other health behaviours
Theory based? If yes what theory?	Yes, Social Cognitive Theory
Duration of intervention total	20 weeks
Follow up 1 (months)	5 months
Follow-up 2 (months)	7.5 months
Gender targeted?	No
SEP targeted?	No

Drummy et al. 2016

Country of implementation	Northern Ireland
Mean age	9.5
Type of school	Primary school
Number of schools total	7 (14 classes)
Level of cluster randomization	Classroom
Education components?	No

Social environment components?	Yes
Physical environment components?	No
Behavioural approach	Targeting PA only
Theory based? If yes what theory?	No
Duration of intervention total	12 weeks
Follow up 1 (months)	3 months
Gender targeted?	No
SEP targeted?	No

Healthy School Start 1

Country of implementation	Sweden
Mean age	6.2 (0.3)
Type of school	Pre-school class
Number of schools total	14
Level of cluster randomization	Classroom
Education components?	Yes
Social environment components?	Yes
Physical environment components?	No
Behavioural approach	PA and other health behaviours
Theory based? If yes what theory?	Yes, SCT
Duration of intervention total	24 weeks
Follow up 1 (months)	6 months
Follow up 2 (months)	12 months
Gender targeted?	No
SEP targeted?	Yes, by school and community SES

Healthy School Start 2

Country of implementation	Sweden
Mean age	6.3 (0.3)
Type of school	Pre-school
Number of schools total	13
Level of cluster randomization	Classroom
Education components?	Yes
Social environment components?	Yes
Physical environment components?	No
Behavioural approach	Multi-behavioural
Theory based? If yes what theory?	Yes. Social Cognitive theory
Duration of intervention total	6
Follow up 1 (months)	6
Follow up 2 (months)	11

Gender targeted?	No
SEP targeted?	Yes

HEIA Study

Country of implementation	Norway
Mean age	11.2 (0.3)
Type of school	Primary schools
Number of schools total	37
Level of cluster randomization	Classoom
Education components?	Yes
Social environment components?	Yes
Physical environment components?	Yes
Behavioural approach	Multi-behavioural
Theory based? If yes what theory?	Yes. Social Ecological Framework
Duration of intervention total	5
Follow up 1 (months)	20
Gender targeted?	No
SEP targeted?	No

KISS

Country of implementation	Switzerland
Mean age	9.25 (0.43)
Type of school	Elementary
Number of schools total	15
Level of cluster randomization	Classroom
Education components?	Yes
Social environment components?	Yes
Physical environment components?	No
Behavioural approach	Targeting PA only
Theory based? If yes what theory?	Yes. Social Ecological Theory
Duration of intervention total	9
Follow up 1 (months)	9
Follow up 2 (months)	36
Gender targeted?	No
SEP targeted?	No

MOVE Project

Country of implementation	UK
Mean age	11.8 (0.5)
Type of school	Secondary schools

Number of schools total	60
Level of cluster randomization	Schools
Education components?	No
Social environment components?	Yes
Physical environment components?	No
Behavioural approach	Targeting PA only
Theory based? If yes what theory?	No.
Duration of intervention total	1.5
Follow up 1 (months)	3
Gender targeted?	No
SEP targeted?	No

NEAT

Country of implementation	Australia
Mean age	13.2 (0.5)
Type of school	Secondary school
Number of schools total	12
Level of cluster randomization	Yes
Education components?	Yes
Social environment components?	Yes
Physical environment components?	No
Behavioural approach	Mulit-behavioural
Theory based? If yes what theory?	Yes. Social cognitive theory
Duration of intervention total	12
Follow up 1 (months)	12
Follow up 2 (months)	24
Gender targeted?	Yes
SEP targeted?	Yes

Physical Activity 4 Everyone

Country of implementation	Austalia
Mean age	12.0
Type of school	Secondary schools
Number of schools total	10
Level of cluster randomization	School
Education components?	Yes
Social environment components?	Yes
Physical environment components?	No
Behavioural approach	Targeting PA only
Theory based? If yes what theory?	Yes. Social Cognitive Theory and Ecological Theory

Duration of intervention total	24
Follow up 1 (months)	24
Gender targeted?	No
SEP targeted?	

SCORES

Country of implementation	Australia
Mean age	8.5 (0.6)
Type of school	Primary schools
Number of schools total	8
Level of cluster randomization	Schools
Education components?	Yes
Social environment components?	Yes
Physical environment components?	No
Behavioural approach	Targeting PA only
Theory based? If yes what theory?	Yes. Self-Determination Theory and Competence Motivation Theory
Duration of intervention total	12
Follow up 1 (months)	12
Gender targeted?	No
SEP targeted?	Yes

SPACE

Country of implementation	Denmark
Mean age	12.5 (0.62)
Type of school	Not specified
Number of schools total	14
Level of cluster randomization	School
Education components?	Yes
Social environment components?	Yes
Physical environment components?	Yes
Behavioural approach	Targeting PA only
Theory based? If yes what theory?	Social Ecological Model
Duration of intervention total	24
Follow up 1 (months)	24
Gender targeted?	No
SEP targeted?	No

The Active Smarter Kids Intervention

Country of implementation	Norway

Mean age	10.2 (0.3)
Type of school	Elementary school
Number of schools total	60
Level of cluster randomization	School
Education components?	Yes
Social environment components?	Yes
Physical environment components?	No
Behavioural approach	Targeting PA only
Theory based? If yes what theory?	No. Social Ecological Framework
Duration of intervention total	7
Follow up 1 (months)	7
Gender targeted?	No
SEP targeted?	YEs

The Bristol Girls Dance Project

Country of implementation	UK
Mean age	11.5
Type of school	Secondary schools
Number of schools total	18
Level of cluster randomization	School
Education components?	No
Social environment components?	Yes
Physical environment components?	No
Behavioural approach	Targeting PA only
Theory based? If yes what theory?	Yes. Self Determination Theory.
Duration of intervention total	5
Follow up 1 (months)	5
Follow up 2 (months)	13
Gender targeted?	Yes
SEP targeted?	No

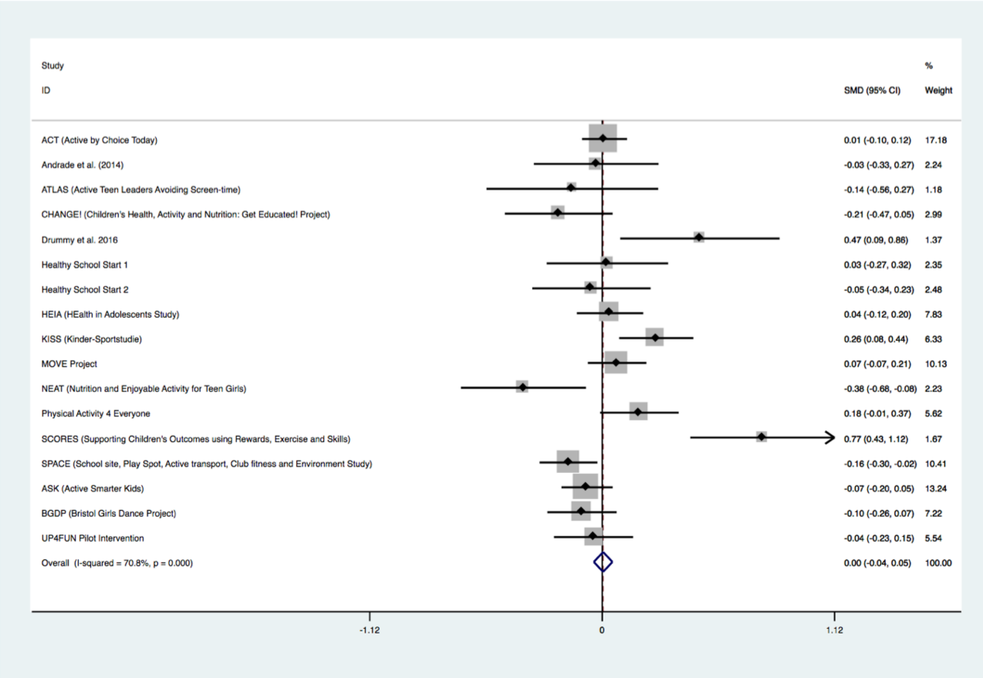
UP 4 Fun Pilot Intervention

Country of implementation	Belgium
Mean age	10.9 (0.7)
Type of school	Primary schools
Number of schools total	10
Level of cluster randomization	School
Education components?	Yes
Social environment components?	Yes
Physical environment components?	No

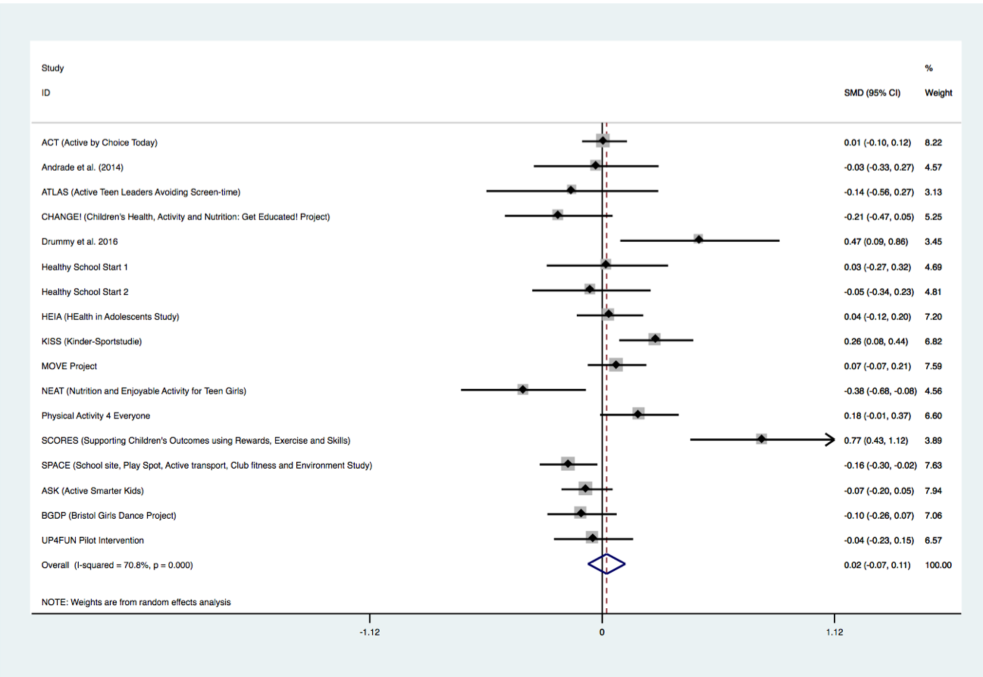
Behavioural approach	Targeting PA only
Theory based? If yes what theory?	Yes. Social Ecological Framework.
Duration of intervention total	1.5
Follow up 1 (months)	1.5
Gender targeted?	No
SEP targeted?	No

A.6.9 All extra figures

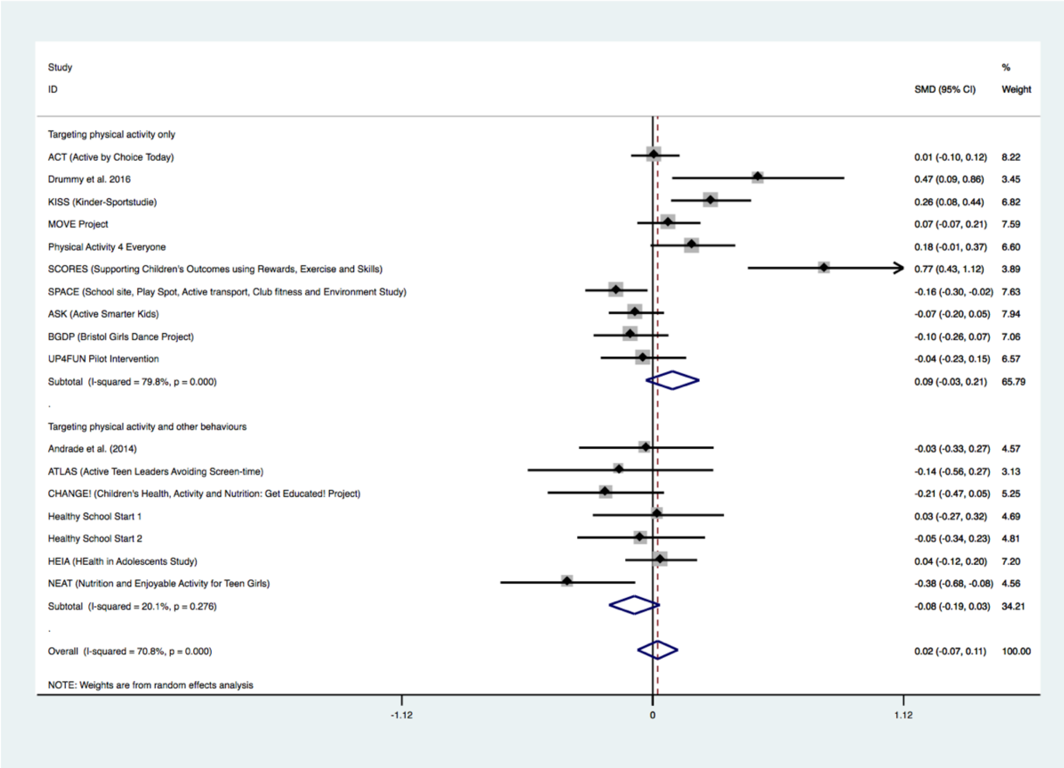
9.1 Main meta-analysis, fixed effects



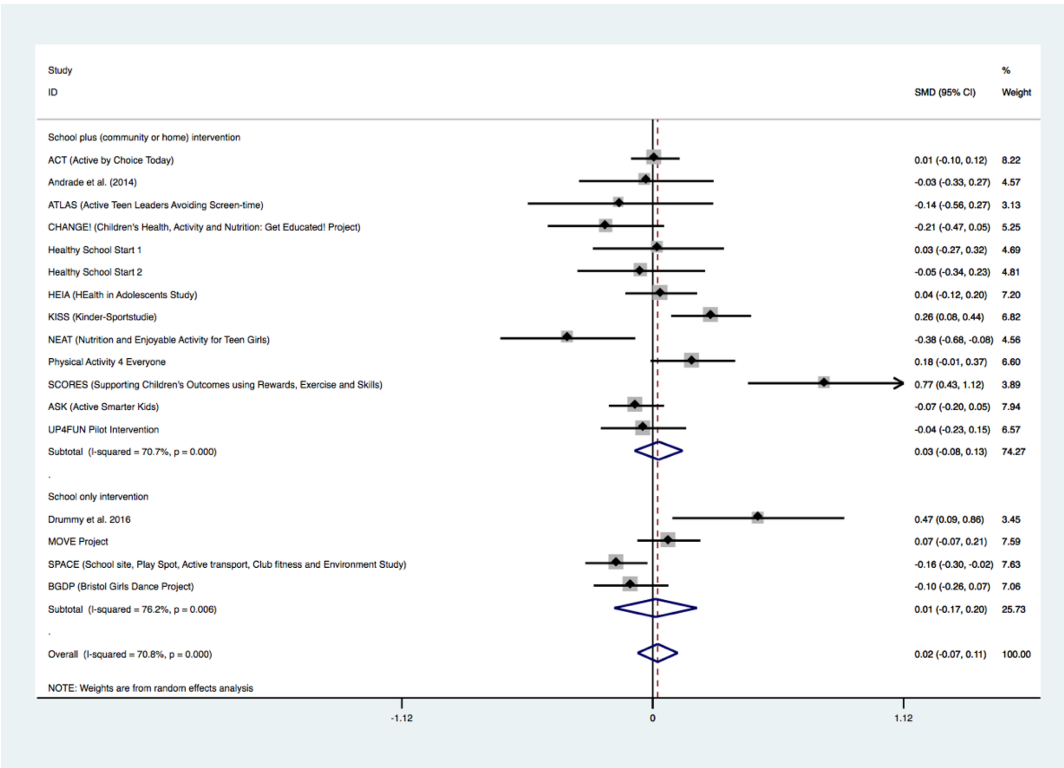
9.2 Main meta-analysis, random effects



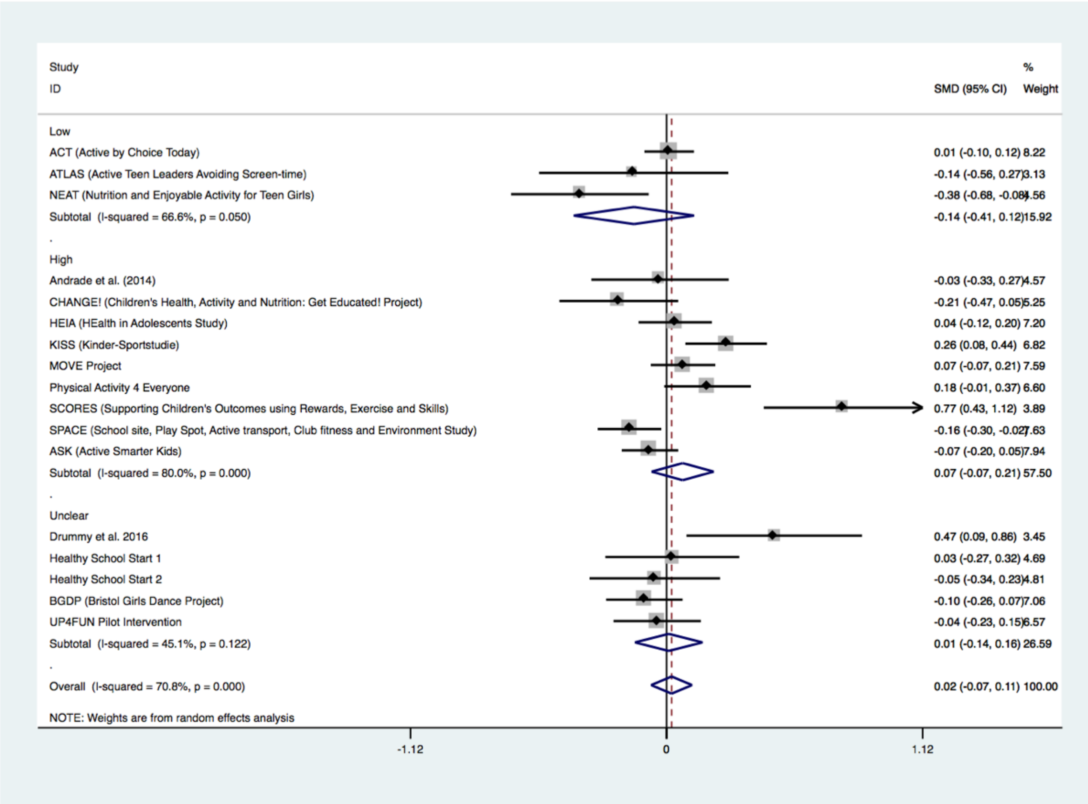
9.3 Main effect subgroup analysis by behavioural approach



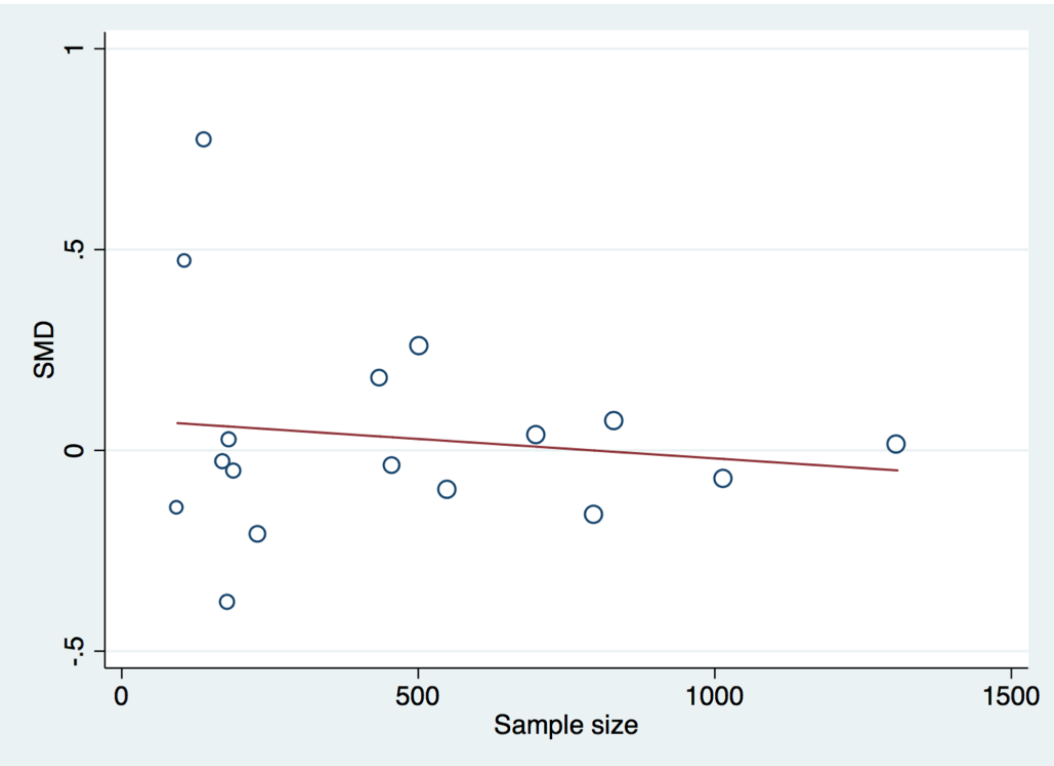
9.4 Main effect subgroup analysis by setting



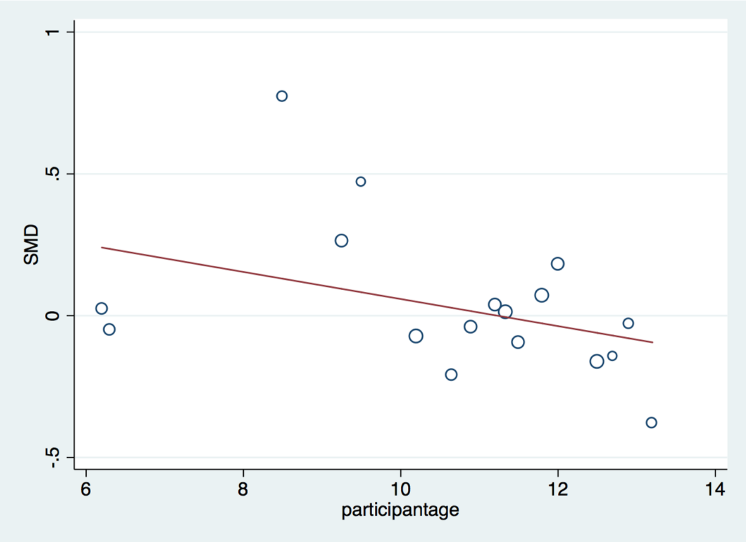
9.5 Main effect subgroup analysis by Risk of Bias Score



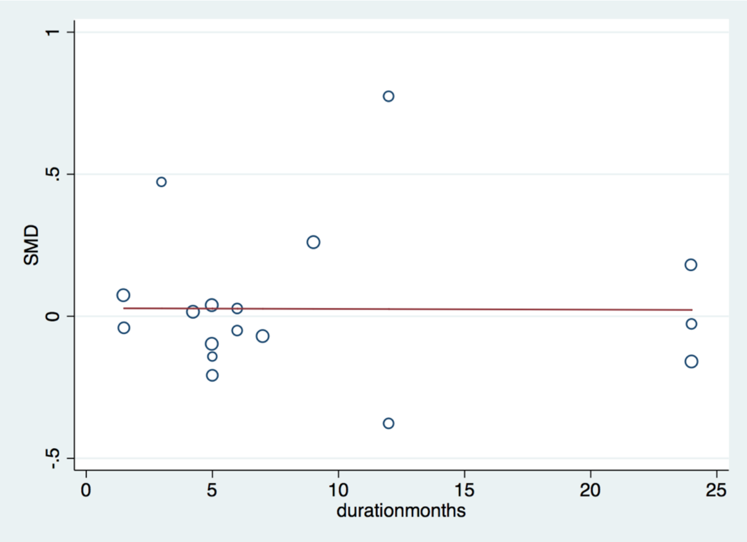
9.6 Main effect meta-regression by sample size (p-value: 0.572)



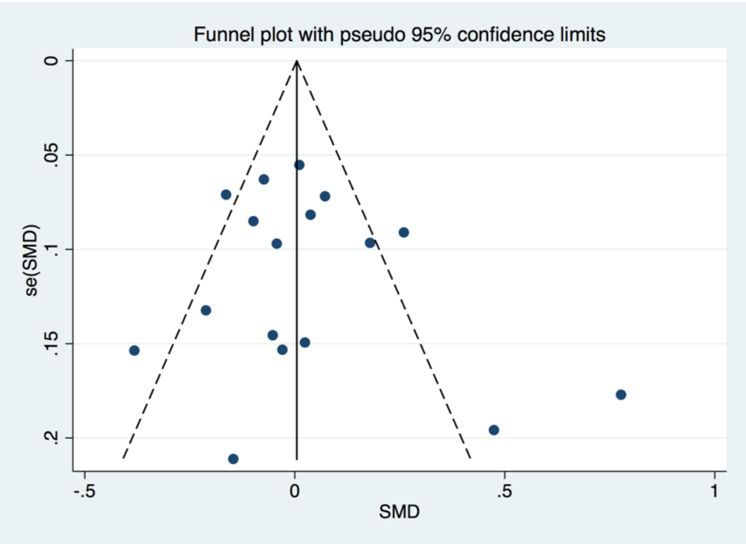
9.7 Main effect meta-regression by participant age (p-value: 0.119)



9.8 Main effect meta-regression by intervention duration (p-value: 0.975)

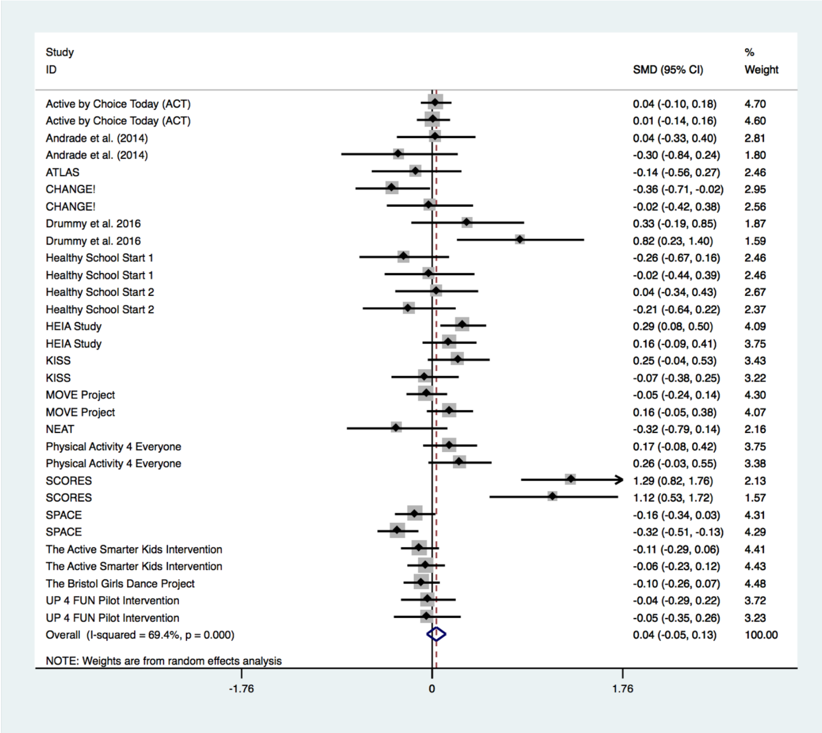


9.9 Main effect meta-analysis funnel plot



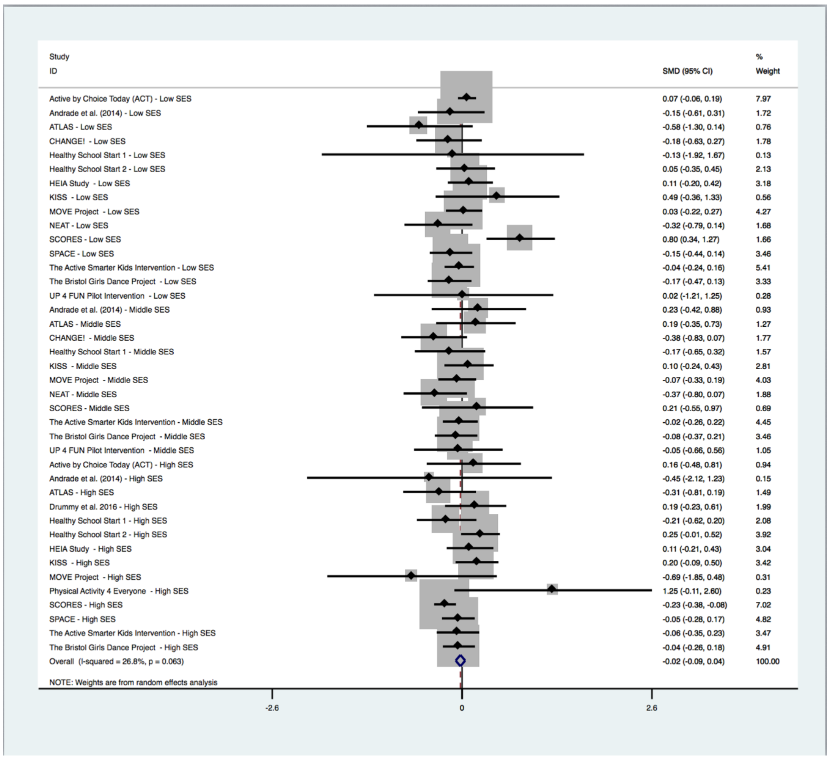
Eggers test (p-value: 0.497)

9.10 Pooled boys and girls meta-analysis and subsequent meta-regression by gender



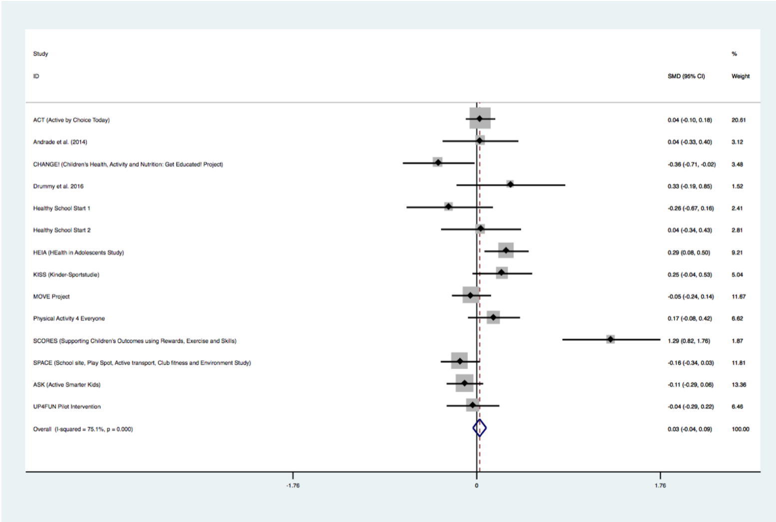
Subsequent meta-regression by gender: Coef: -0.0043184, p-value: 0.972

9.11 Pooled SEP tertiles meta-analysis and subsequent meta-regression by SEP

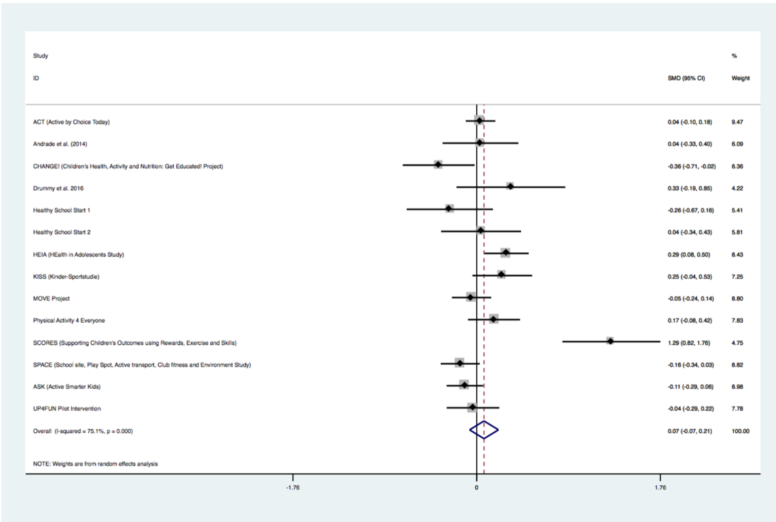


Subsequent meta-regression by SEP: Coef: -0.018218, p-value: 0.679)

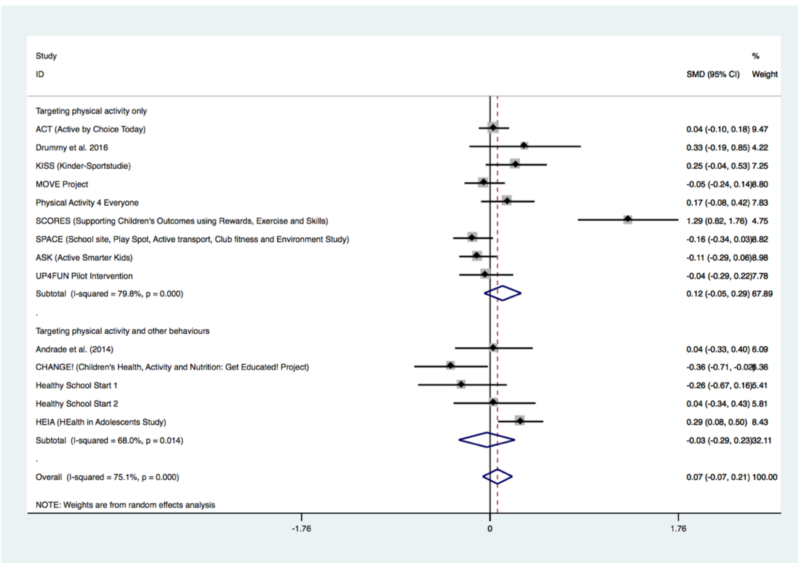
9.12 Girls meta-analysis, fixed effects



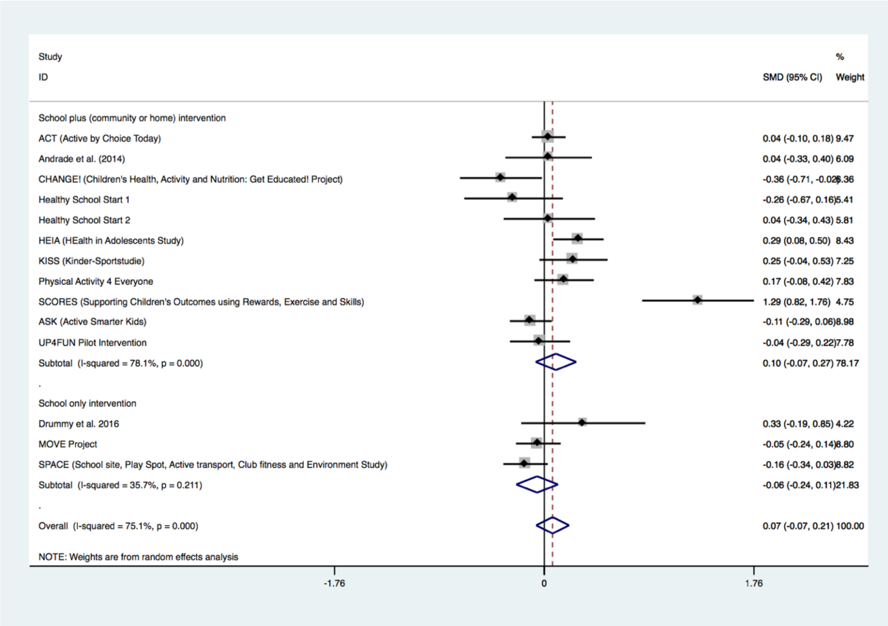
9.13 Girls meta-analysis, random effects



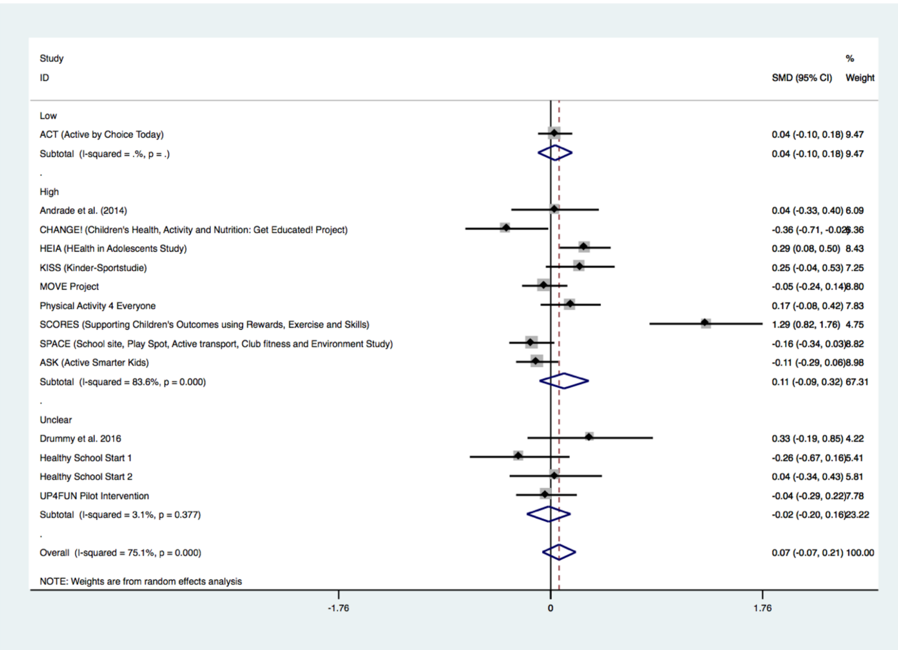
9.14 Girls effect subgroup analysis by behavioural approach



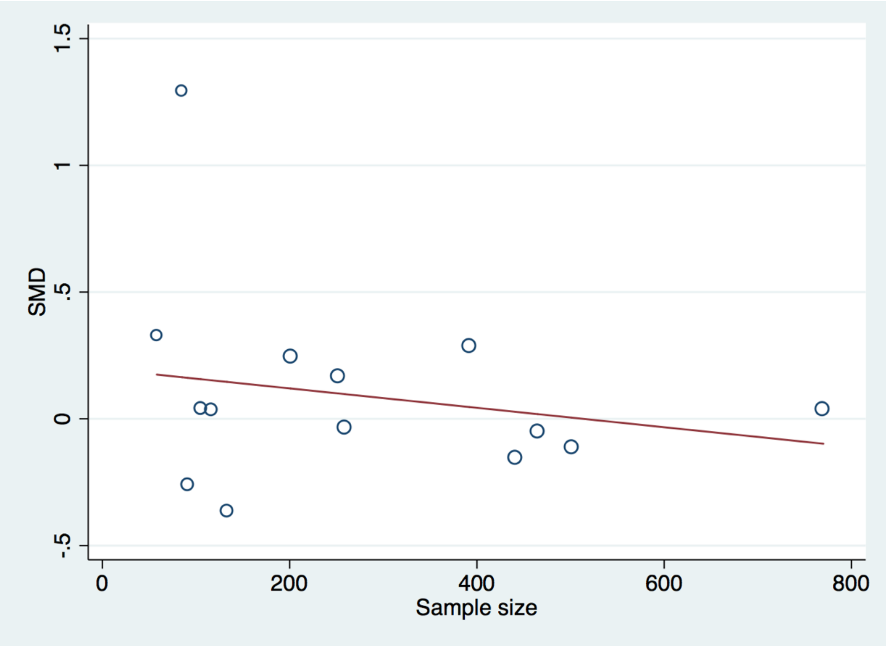
9.15 Girls effect subgroup analysis by intervention setting



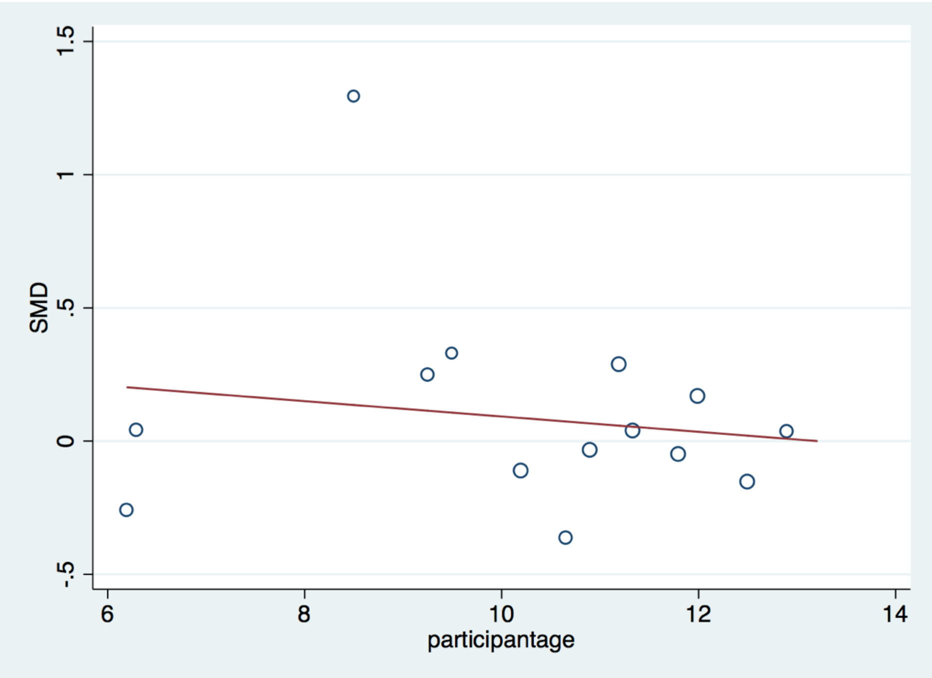
9.16 Girls effect subgroup analysis by risk of bias



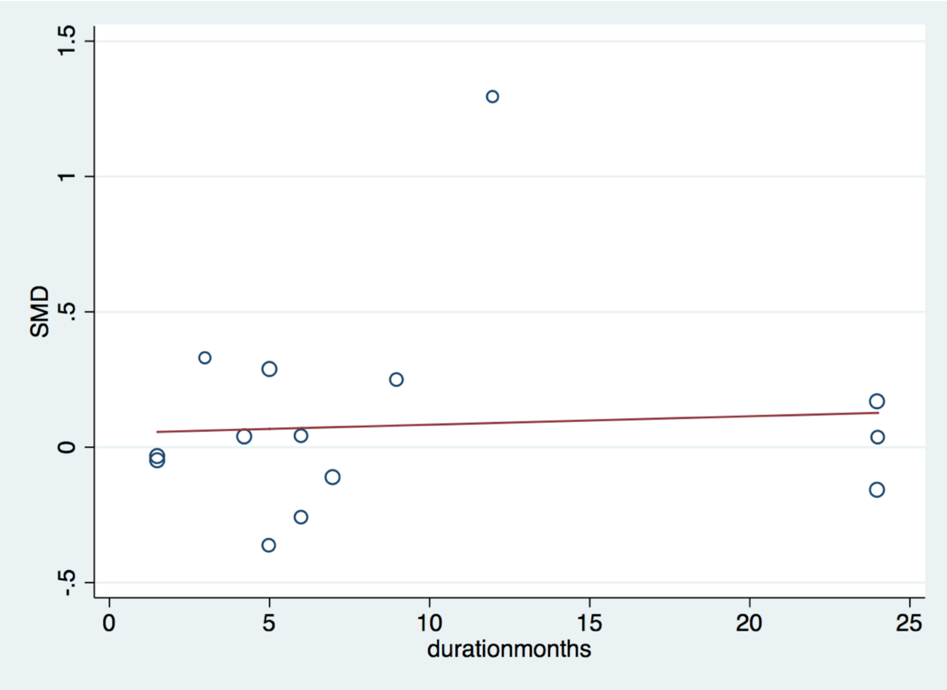
9.17 Girls effect meta-regression by sample size (p-value: 0.435)



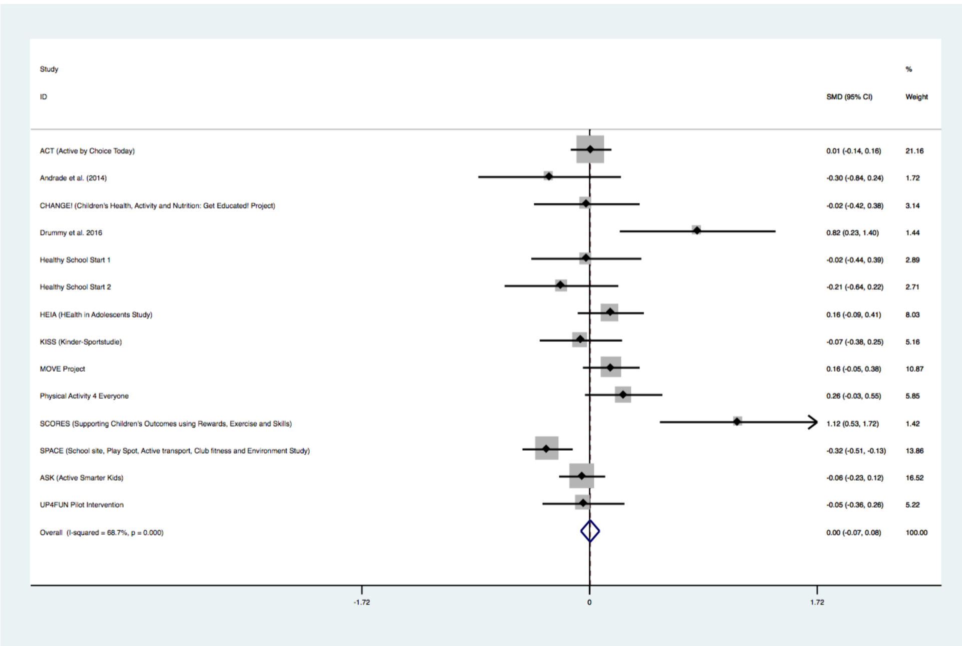
9.18 Girls effect meta-regression by participant age (p-value: 0.584)



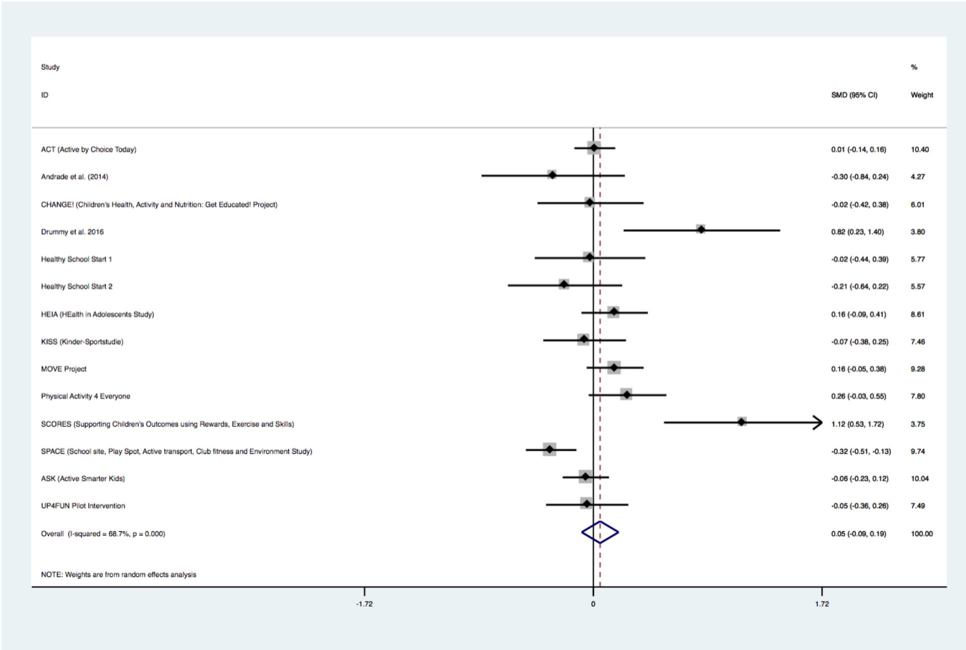
9.19 Girls effect meta-regression by intervention duration (p-value:0.804)



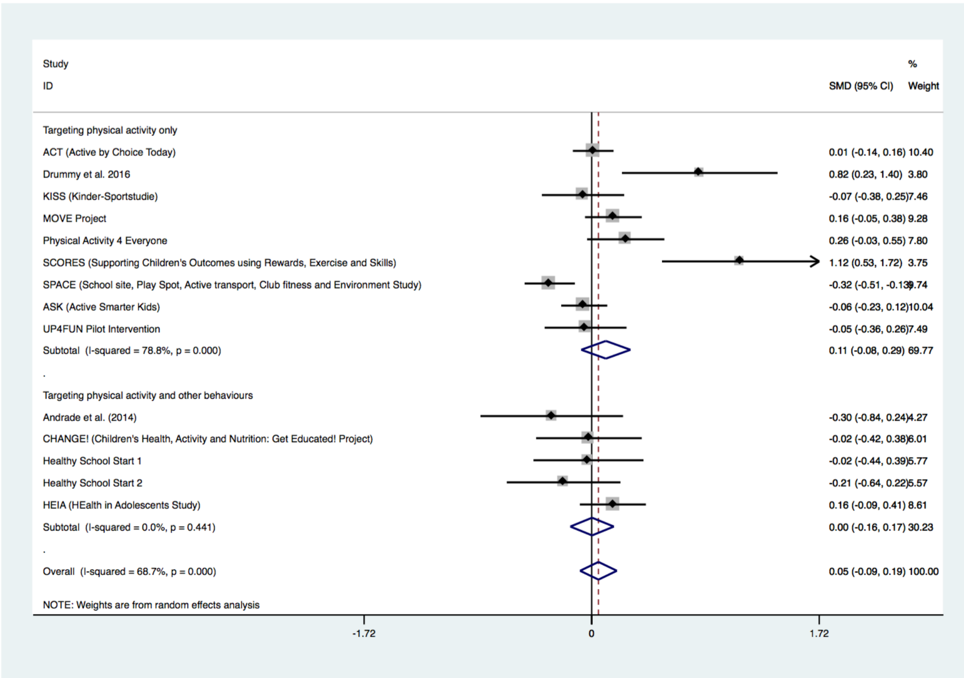
9.20 Boys meta-analysis, fixed effects



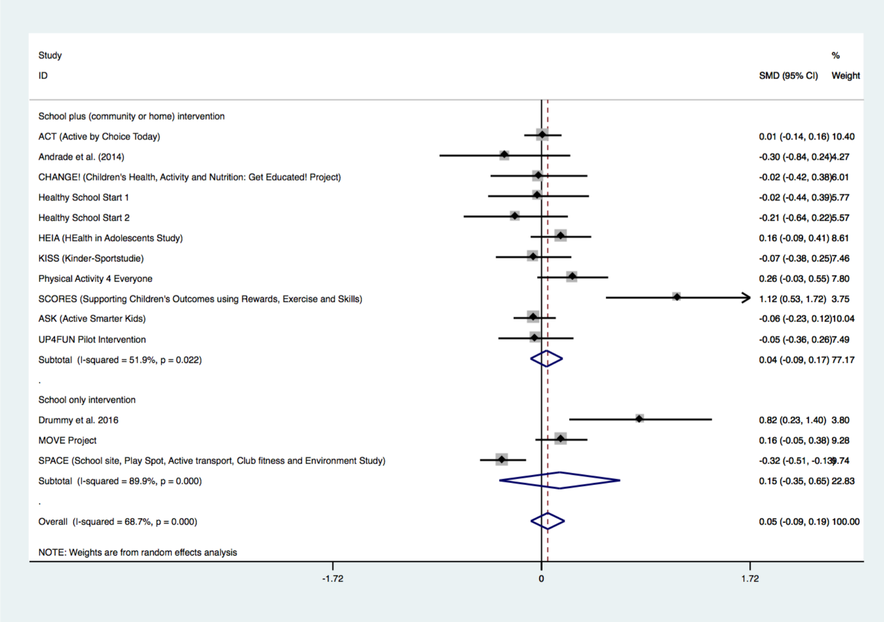
9.21 Boys meta-analysis, random effects



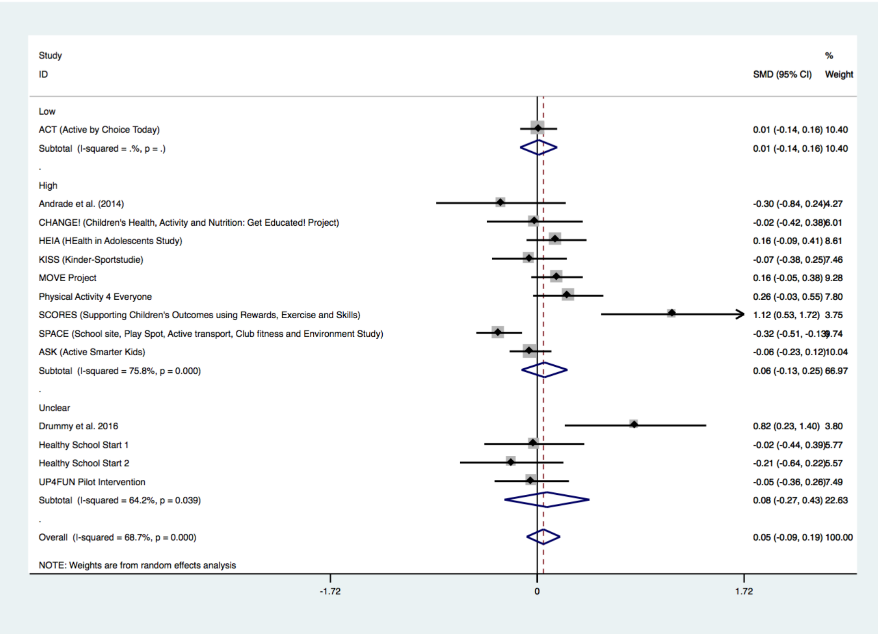
9.22 Boys effect subgroup analysis by behavioural approach



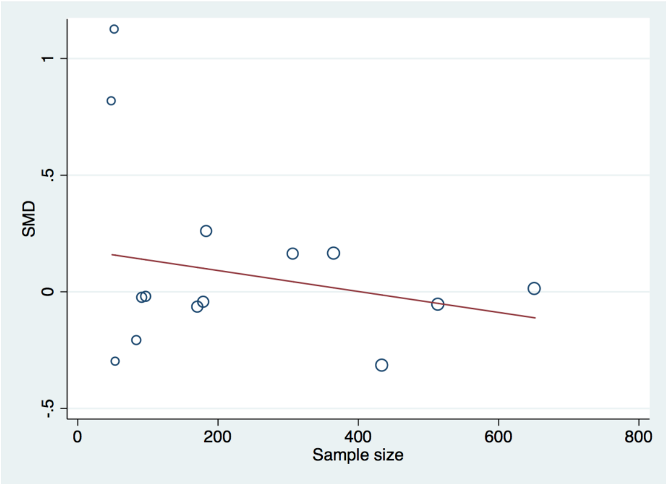
9.23 Boys effect subgroup analysis by intervention setting



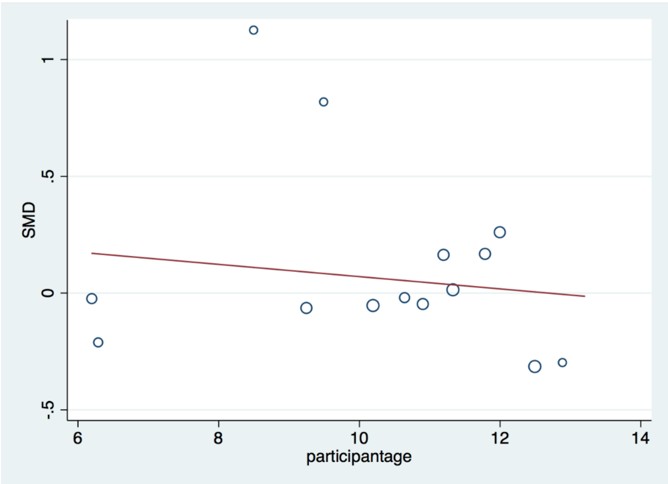
9.24 Boys effect subgroup analysis by risk of bias



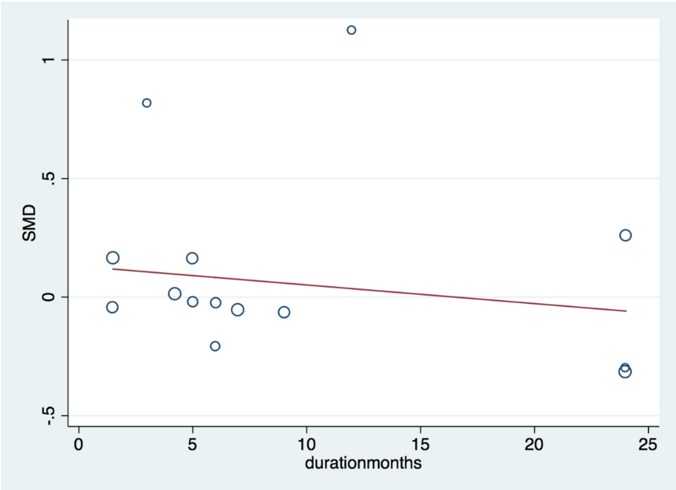
9.25 Boys effect meta-regression by sample size (p-value: 0.349)



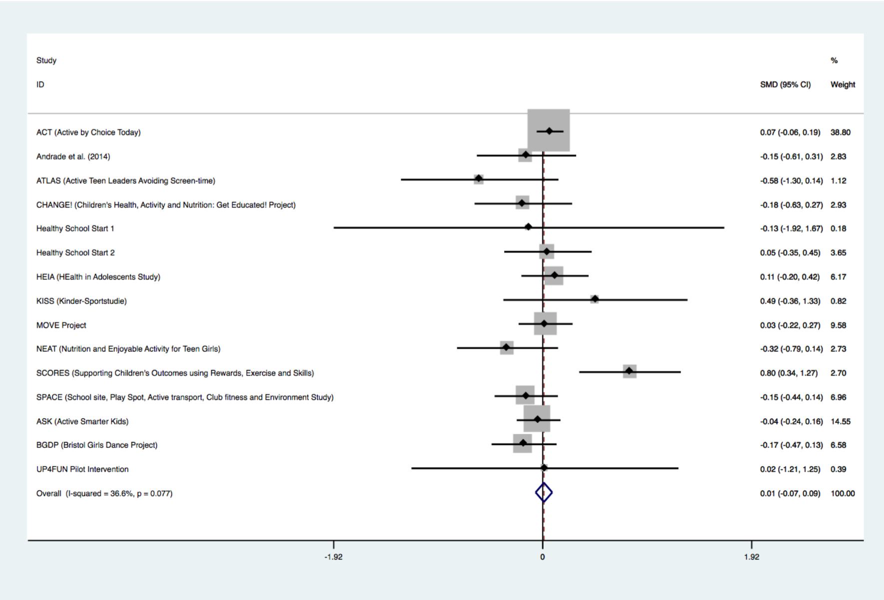
9.26 Boys effect meta-regression by participant age (p-value: 0.600)



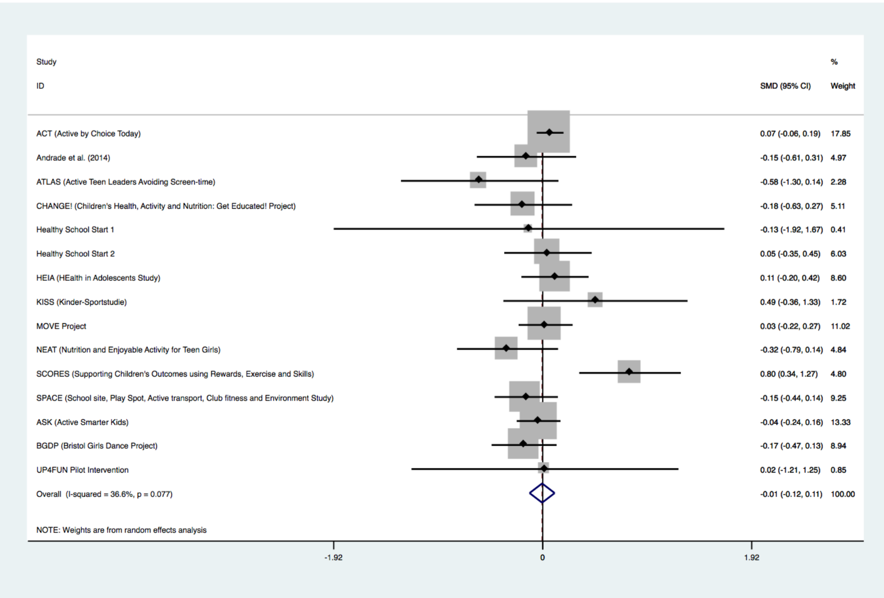
9.27 Boys effect meta-regression by intervention duration (p-value: 0.494)



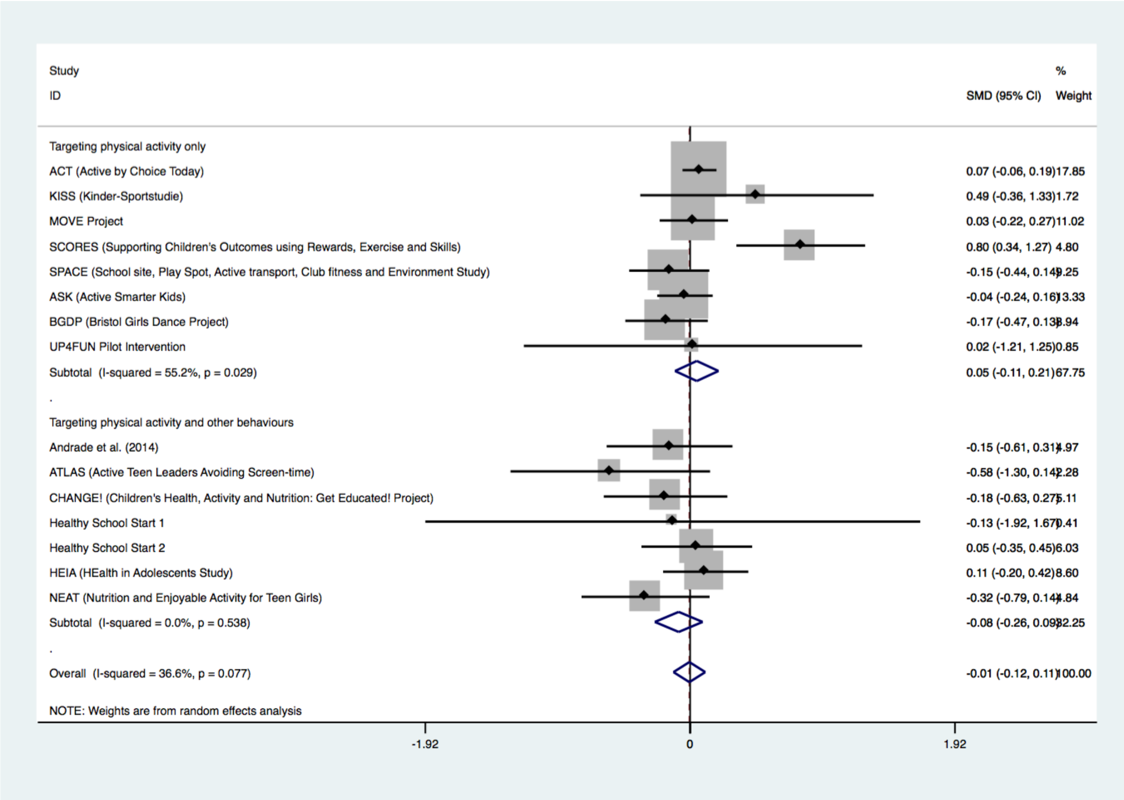
9.28 Low SEP meta-analysis, fixed effects



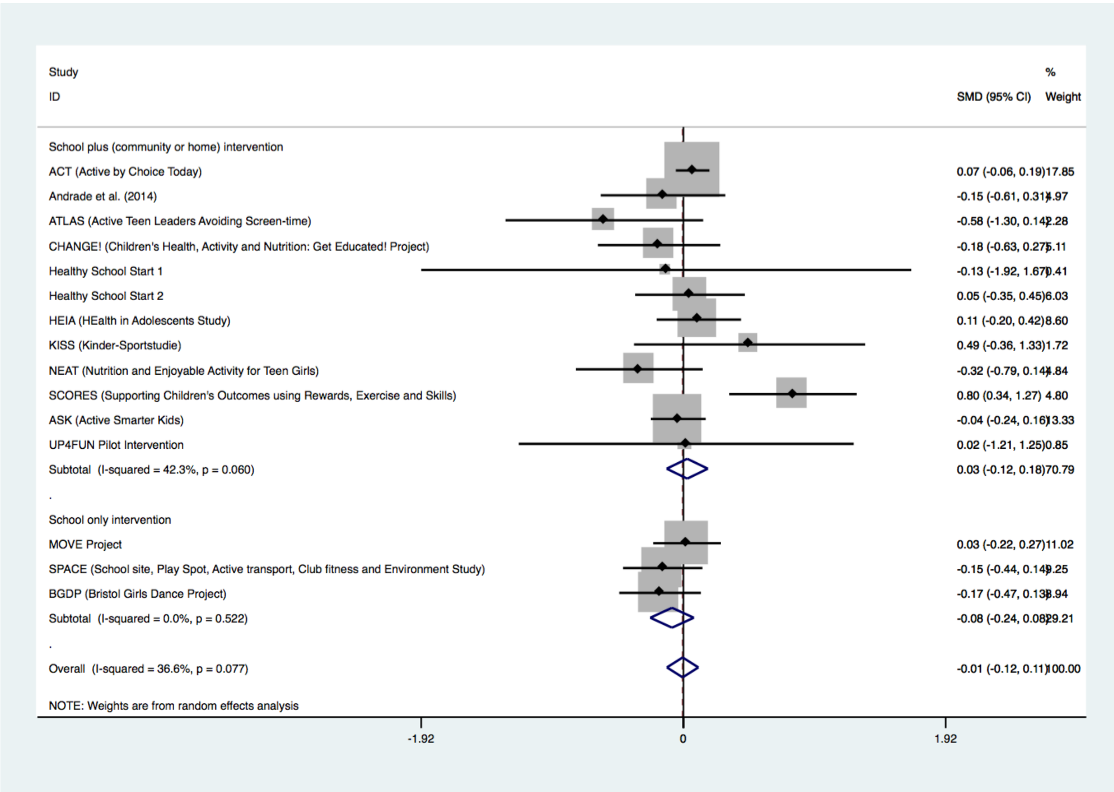
9.29 Low SEP meta-analysis, random effects



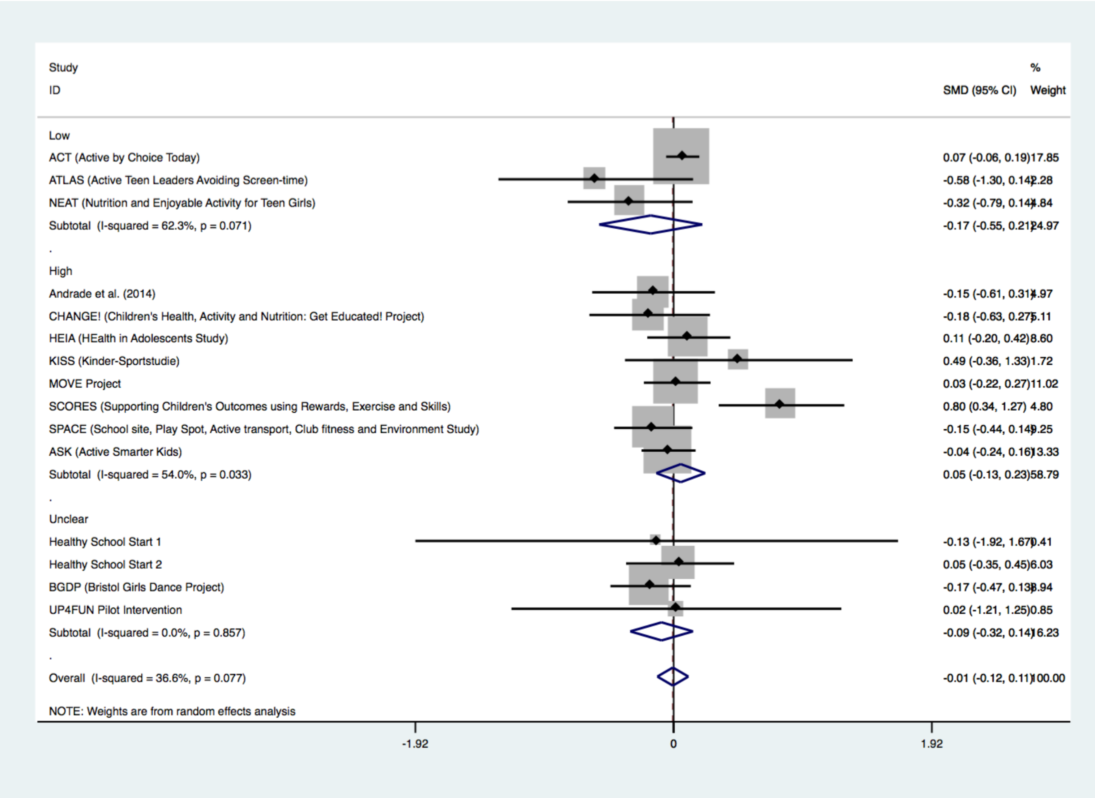
9.30 Low SEP effect subgroup analysis by behavioural approach



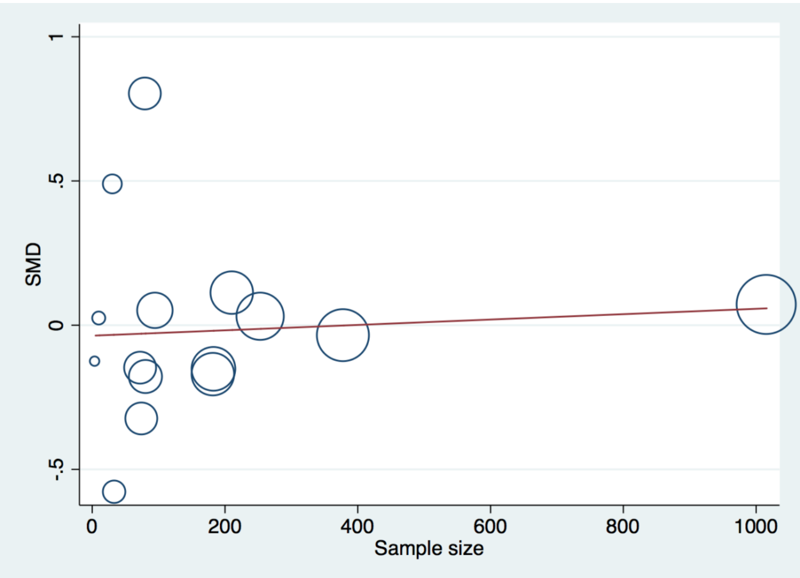
9.31 Low SEP effect subgroup analysis by intervention setting



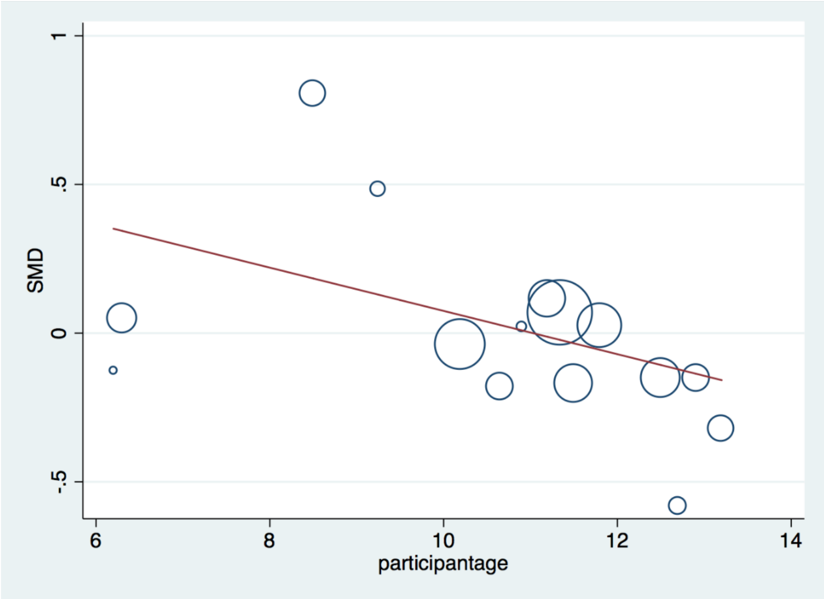
9.32 Low SEP effect subgroup analysis by risk of bias



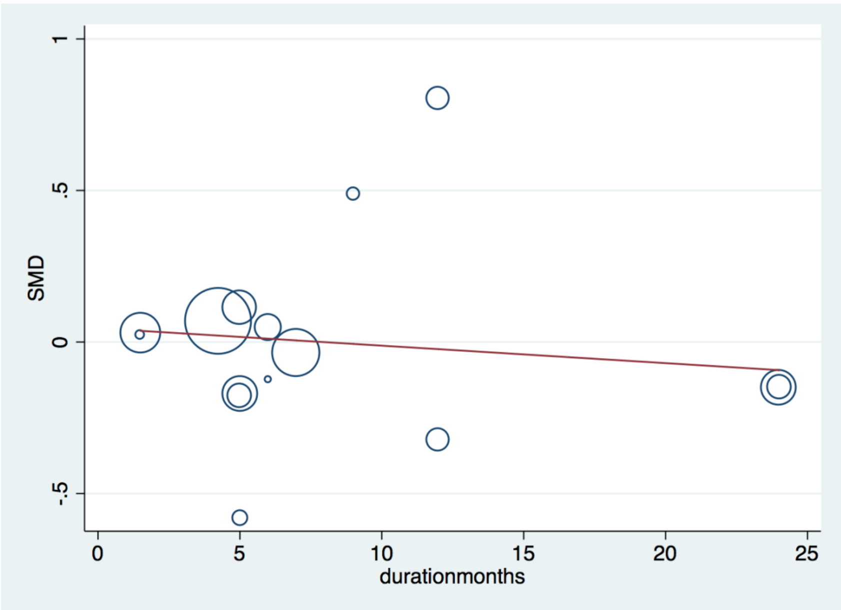
9.33 Low SEP effect meta-regression by sample size (p-value: 0.654)



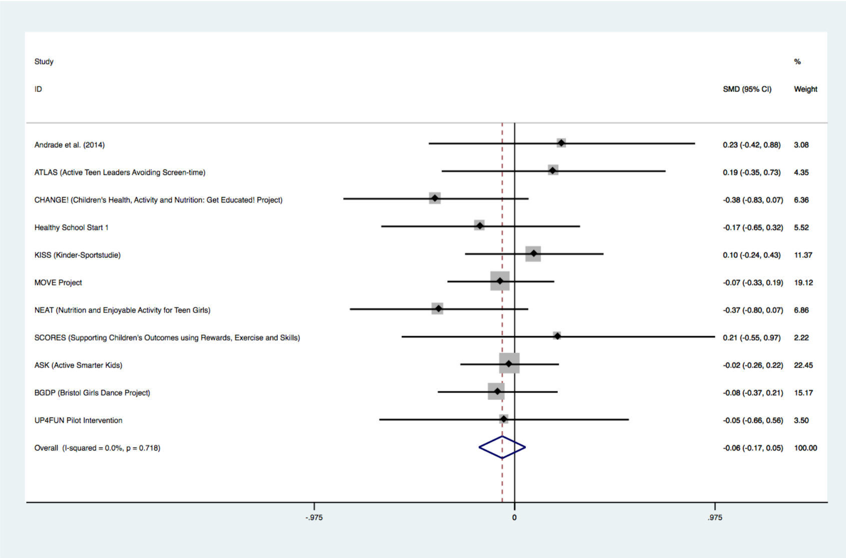
9.34 Low SEP effect meta-regression by participant age (p-value: 0.055)



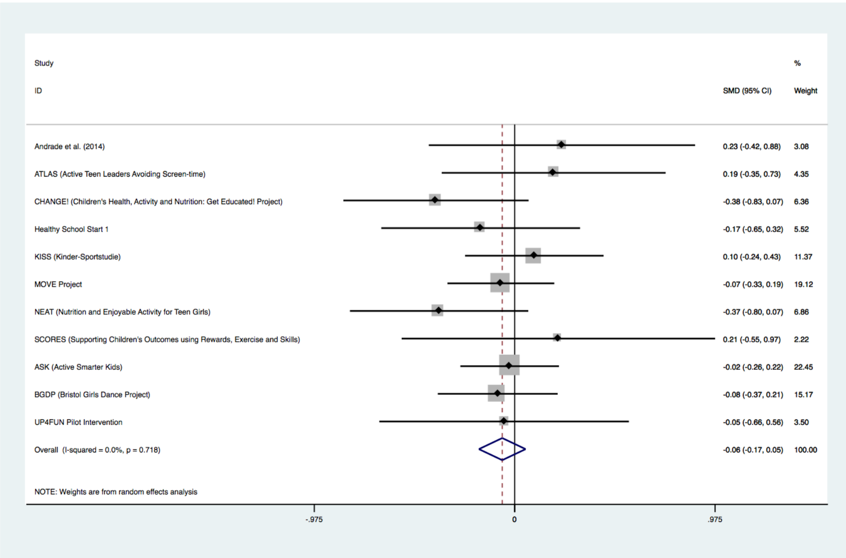
9.35 Low SEP effect meta-regression by intervention duration (p-value: 0.517)



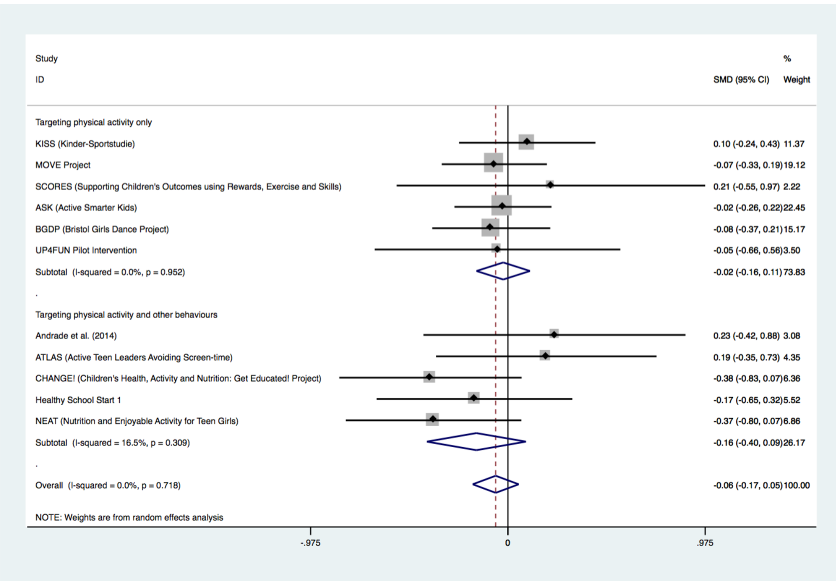
9.36 Middle SEP meta-analysis, fixed effects



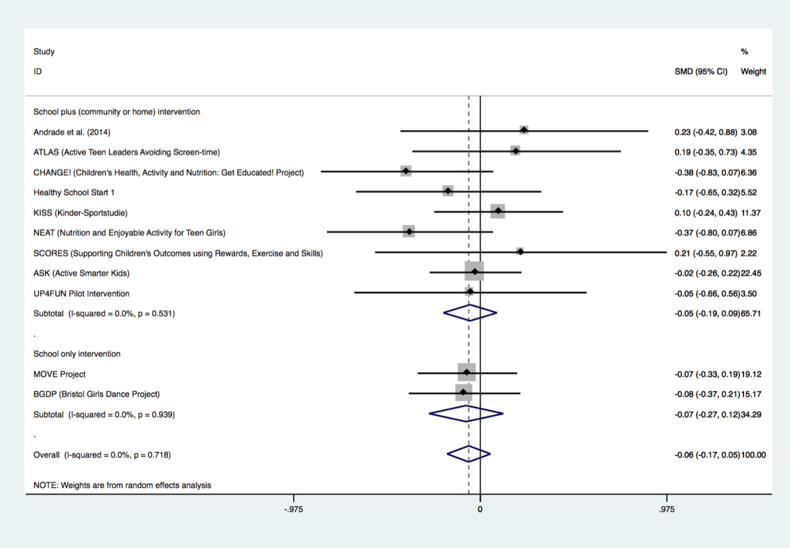
9.37 Middle SEP meta-analysis, random effects



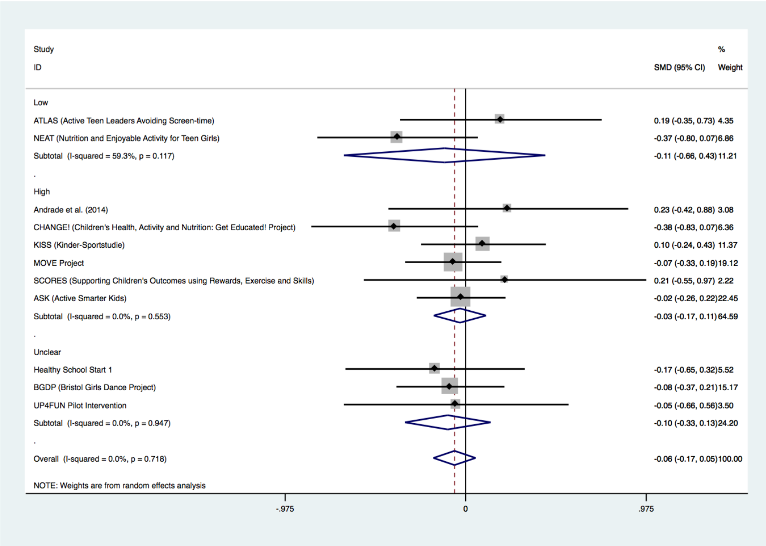
9.38 Middle SEP effect subgroup analysis by behavioural approach



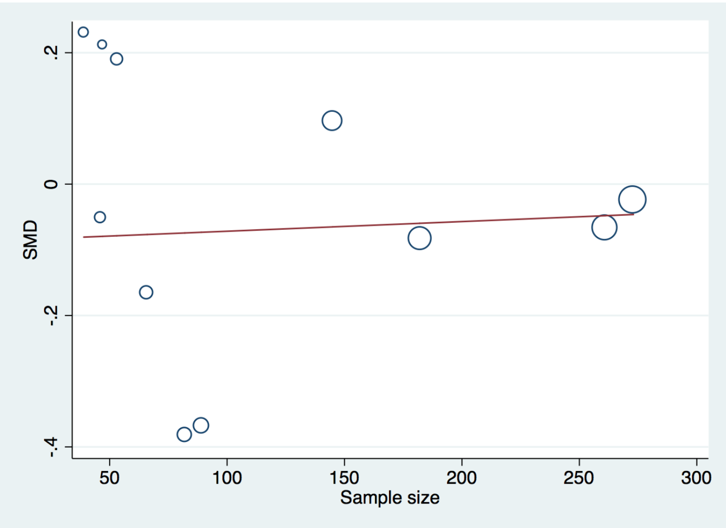
9.39 Middle SEP effect subgroup analysis by intervention setting



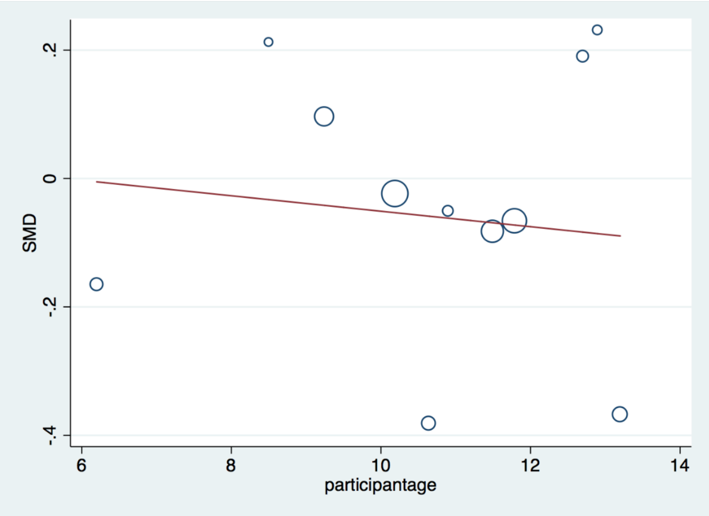
9.40 Middle SEP effect subgroup analysis by risk of bias



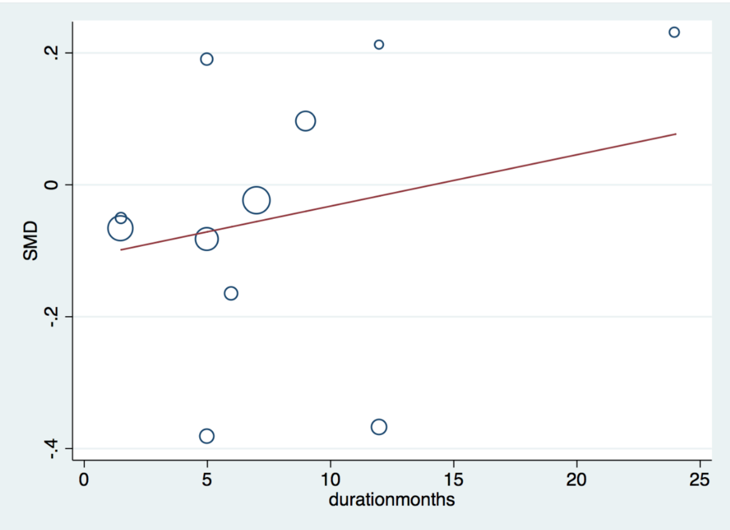
9.41 Middle SEP effect meta-regression by sample size (p-value: 0.830)



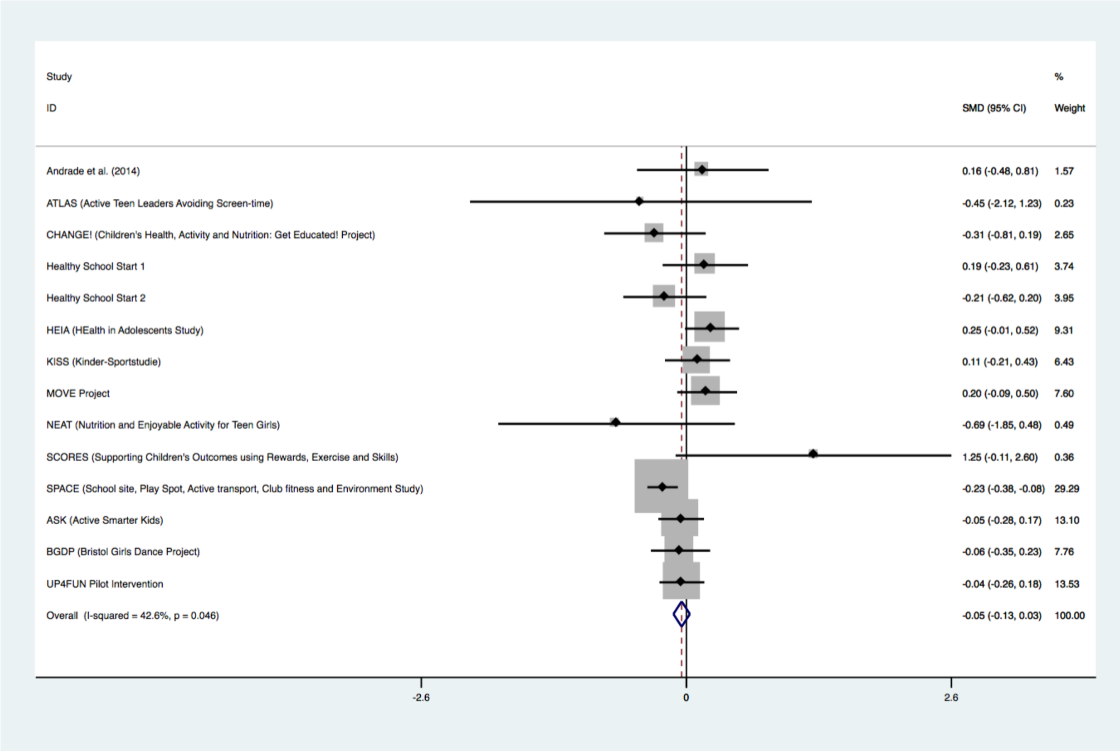
9.42 Middle SEP effect meta-regression by participant age (p-value: 0.745)



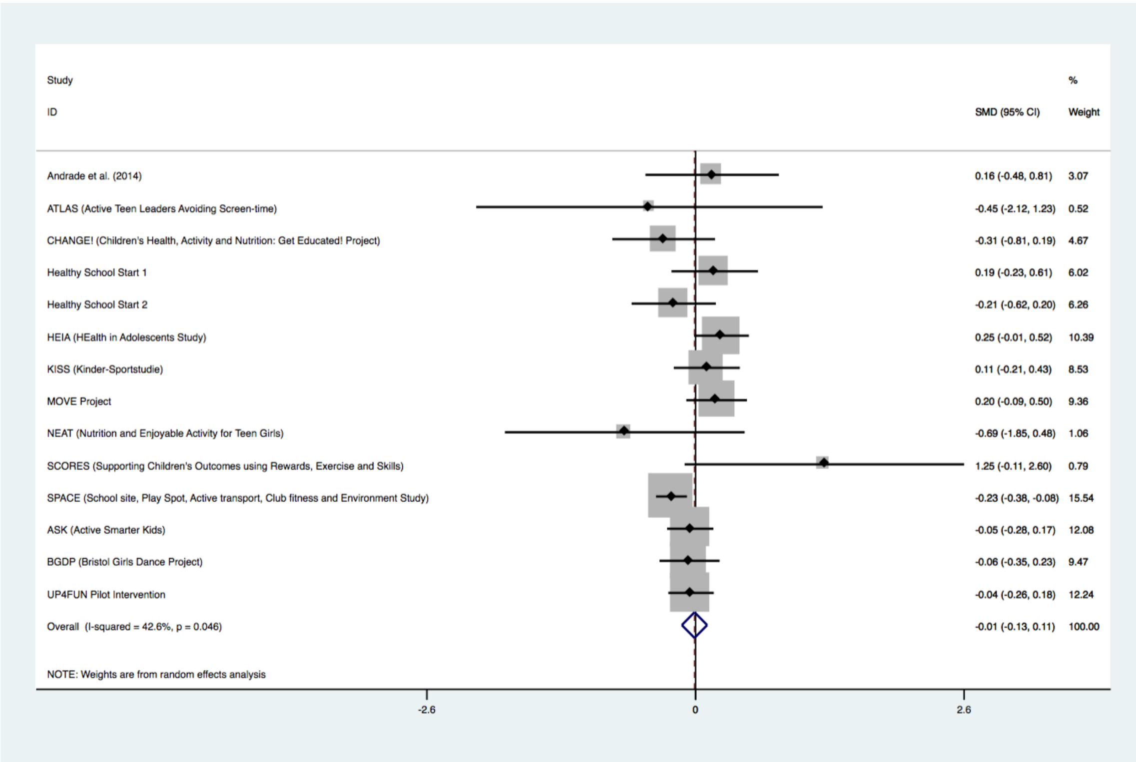
9.43 Middle SEP effect meta-regression by intervention duration (p-value: 0.570)



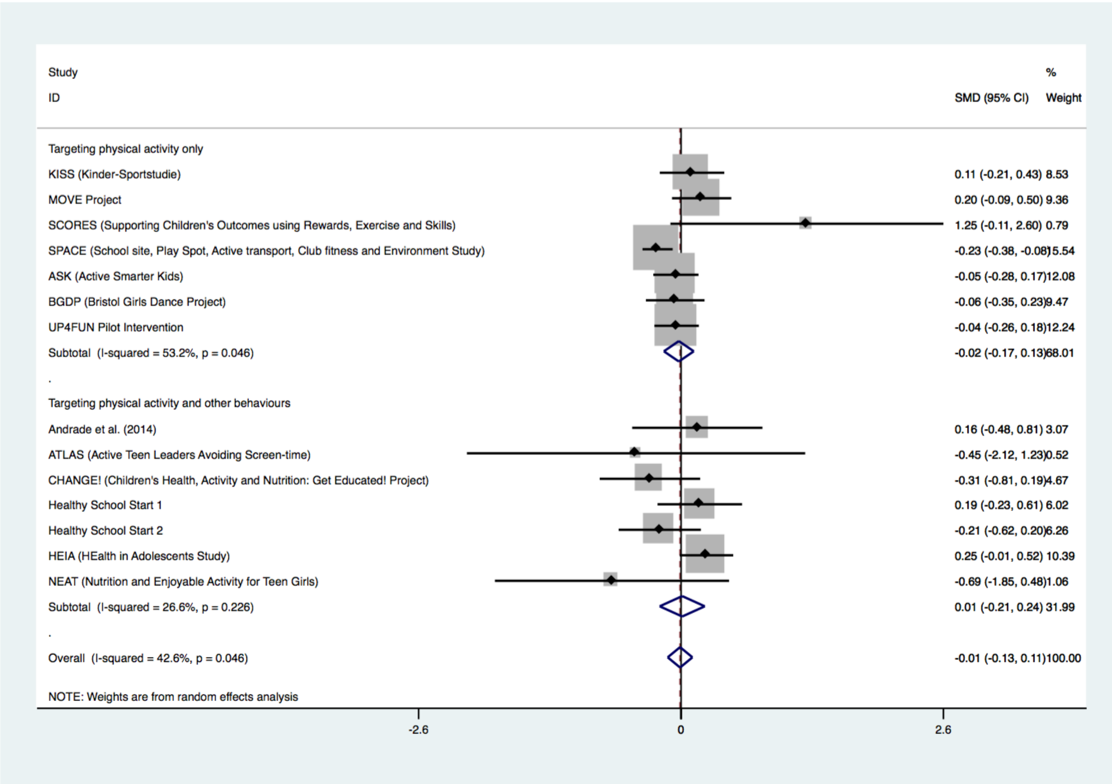
9.44 High SEP meta-analysis, fixed effects



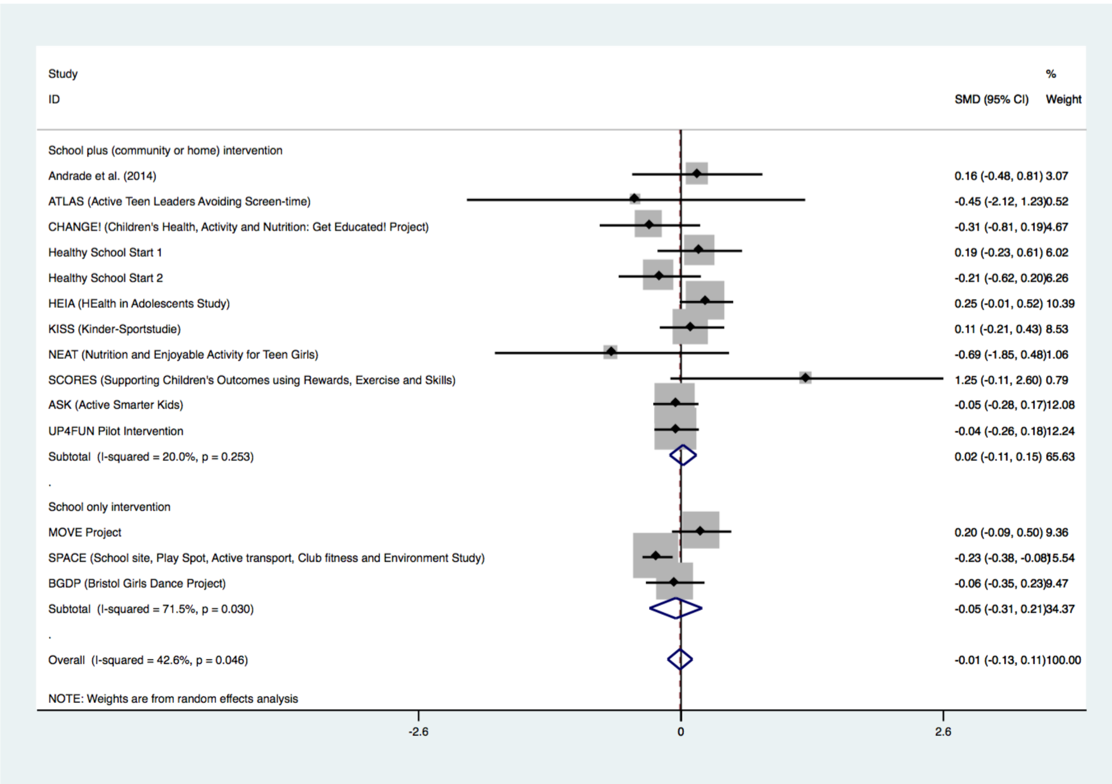
9.45 High SEP meta-analysis, random effects



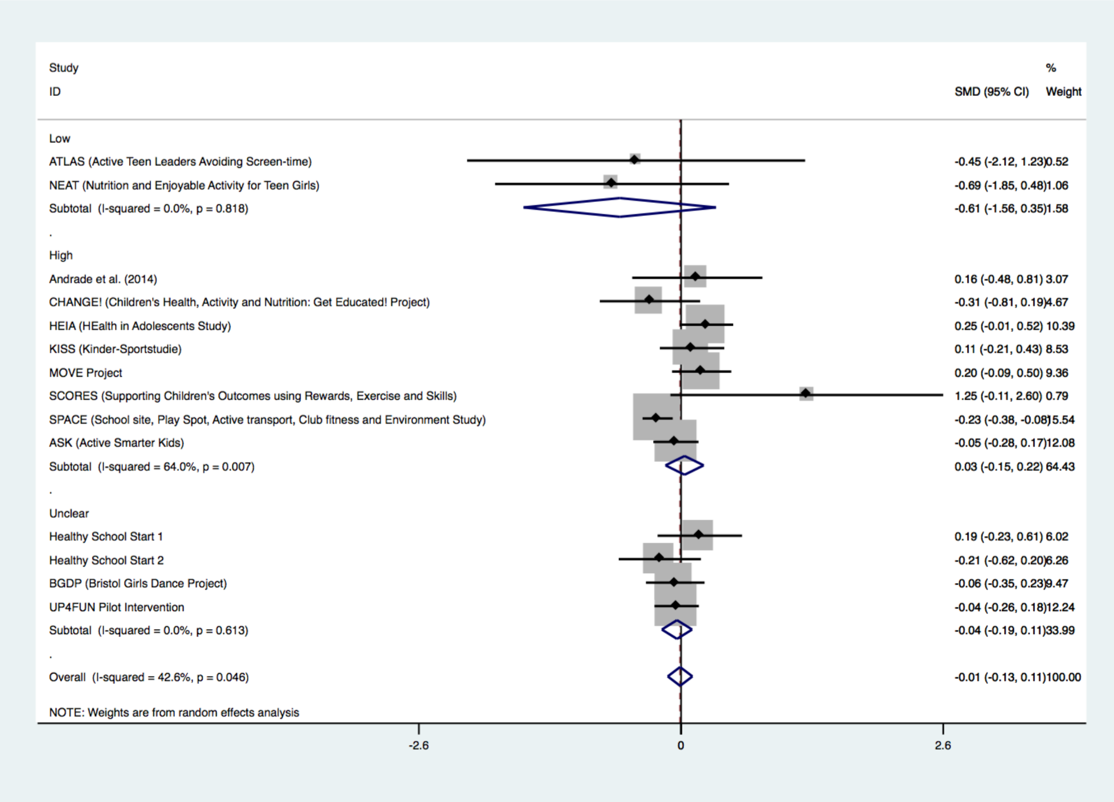
9.46 High SEP effect subgroup analysis by behavioural approach



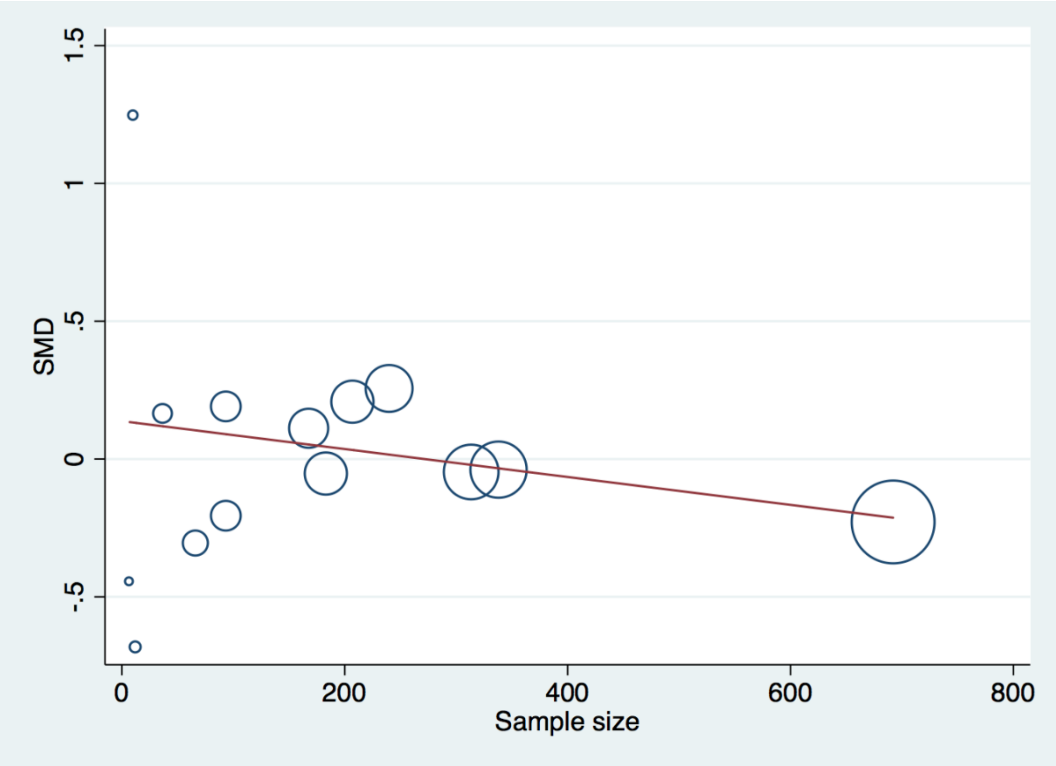
9.47 High SEP effect subgroup analysis by intervention setting



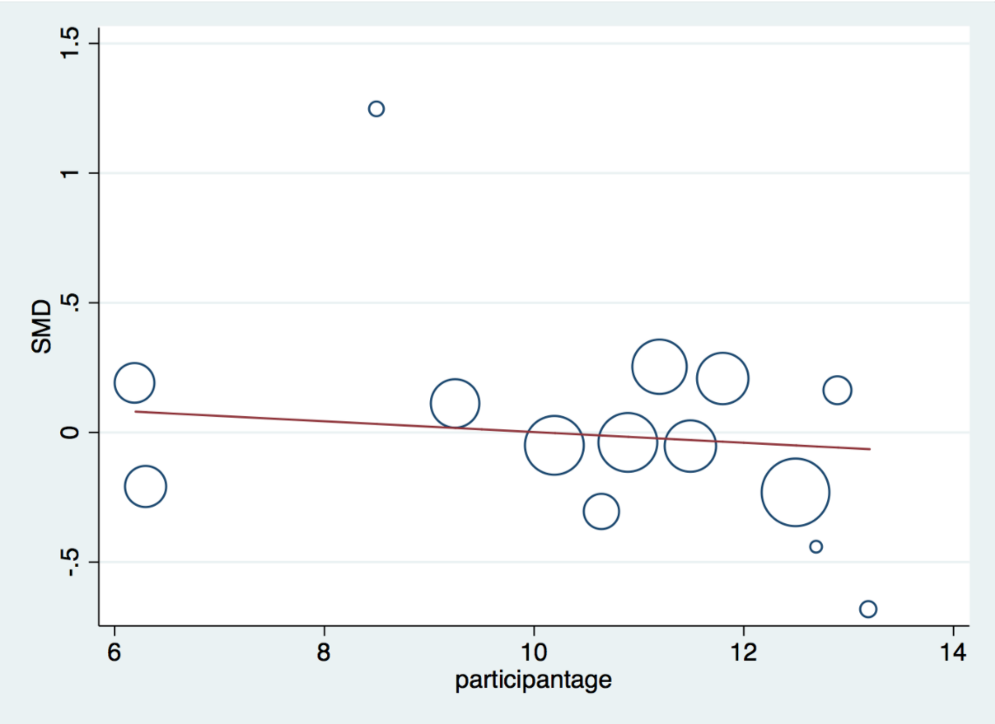
9.48 High SEP effect subgroup analysis by risk of bias



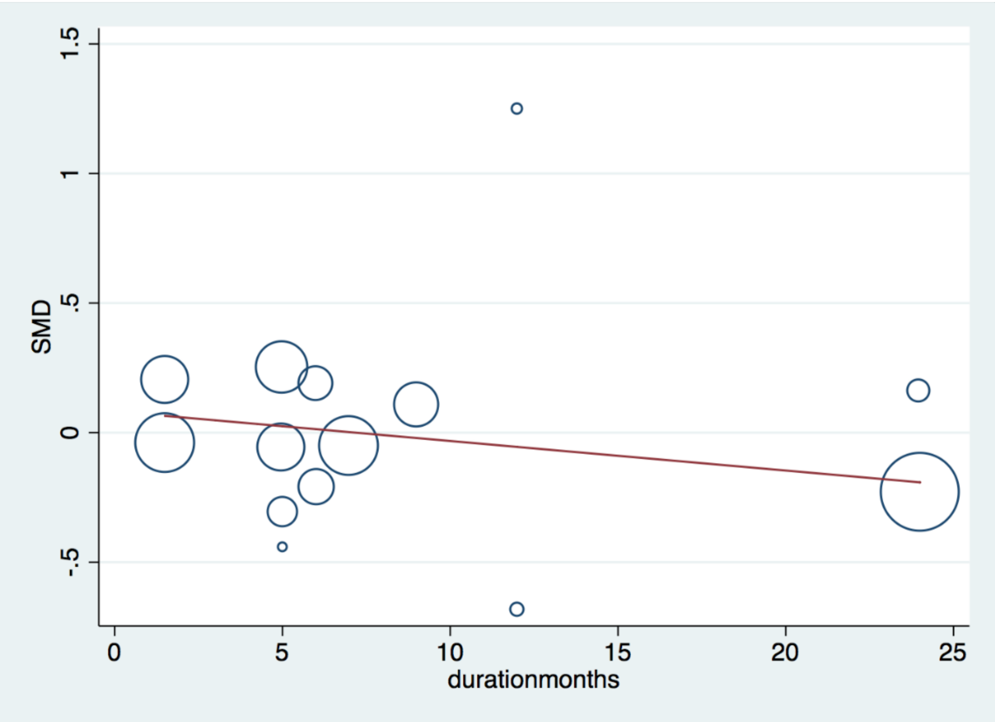
9.49 High SEP effect meta-regression by sample size (p-value: 0.029)**



9.50 High SEP effect meta-regression by participant age (p-value: 0.542)



9.51 High SEP effect meta-regression by intervention duration (p-value: 0.082)



A.6.10 Failsafe ratio of included trials

Trial	Failsafe Number
Active by Choice Today (ACT)	0.369393432
Andrade et al. (2014)	1.987772818
ATLAS	1.016884684
CHANGE!	6.007396298
Drummy et al. 2016	14.1020013
Healthy School Start 1	8.93322253
Healthy School Start 2	4.891004555
HEIA Study	-2.146305388
KISS	8.569520859
MOVE Project	18.66453466
NEAT	9.350694747
Physical Activity 4 Everyone	15.68801568
SCORES	19.14505705
SPACE	4.570687241
The Active Smarter Kids Intervention	11.43396927
The Bristol Girls Dance Project	23.05178785
UP 4 FUN Pilot Intervention	19.85089856

* Trials are added in the order to which they appear in the meta-analysis

A.6.11 Risk of Bias assessment of included studies

	Random sequence generation	**Allocation concealment**	**Blinding of assessors at baseline**	**Incomplete outcome data**	**Selective Reporting**
Active by Choice Today (ACT)	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias
Andrade (2014)	Low risk of bias	High risk of bias	Low risk of bias	Low risk of bias	Unclear risk of bias
ATLAS RCT	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Unclear risk of bias
Change!	Low risk of bias	High risk of bias	High risk of bias	High risk of bias	High risk of bias
Drummy et al. (2016)	Unclear risk of bias	Unclear risk of bias	Unclear risk of bias	High risk of bias	Unclear risk of bias
Healthy School Start Study	Unclear risk of bias	Low risk of bias	Unclear risk of bias	Low risk of bias	Low risk of bias
Healthy School Start Study II	Low risk of bias	Low risk of bias	Unclear risk of bias	Low risk of bias	Low risk of bias
HEIA study	Low risk of bias	Low risk of bias	High risk of bias	High risk of bias	Low risk of bias
KISS	Low risk of bias	High risk of bias	Low risk of bias	Low risk of bias	Low risk of bias
MOVE Project	Low risk of bias	Low risk of bias	Unclear risk of bias	High risk of bias	Unclear risk of bias
NEAT girls	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias
Physical Activity 4 Everyone	Low risk of bias	Low risk of bias	Low risk of bias	High risk of bias	Low risk of bias
SCORES	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	High risk of bias
SPACE Study	Unclear risk of bias	High risk of bias	Unclear risk of bias	Unclear risk of bias	High risk of bias
The Active Smarter Kids Intervention	Unclear risk of bias	Unclear risk of bias	Unclear risk of bias	High risk of bias	High risk of bias
The Bristol Girls Dance Project	Unclear risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias
UP4FUN pilot intervention (2012)	Low risk of bias	Unclear risk of bias	Unclear risk of bias	High risk of bias	Unclear risk of bias